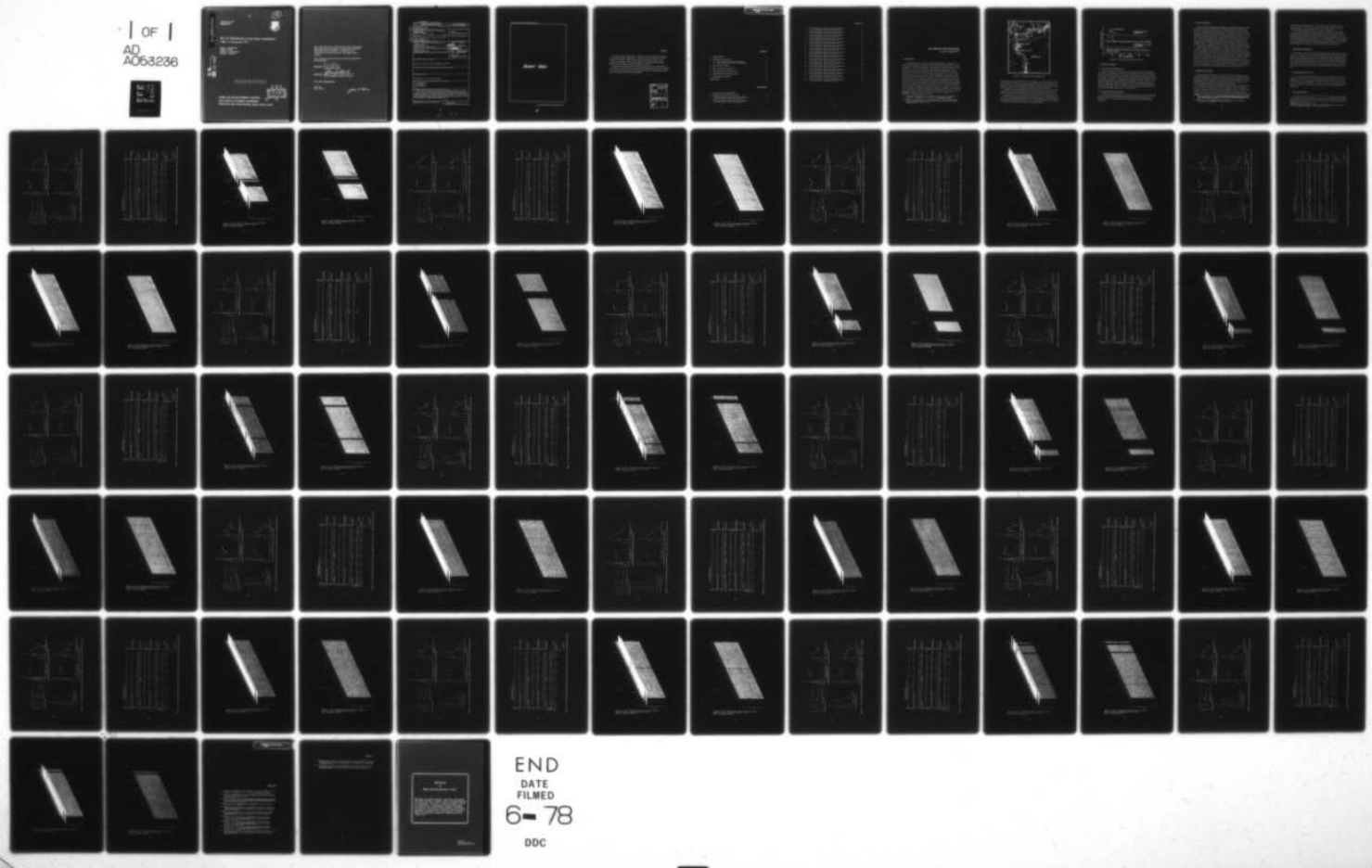
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RADC-TR-77-428
IN-HOUSE REPORT
DECEMBER 1977

VLF/LF Reflectivity of the Polar Ionosphere

1 May—3 September 1977

JOHN E. RASMUSSEN
JOHN P. TURTLE
ROBERT P. PAGLIARULO
WAYNE I. KLEMETTI

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E. A. Lewis.

Approved: E. A. Lewis, Chief
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Allan C. Schell

Approved: Allan C. Schell, Acting Chief
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides a summary of high latitude ionospheric reflectivity as observed by the USAF high resolution VLF/LF ionosounder operating in northern Greenland. Ionospheric reflectivity parameters, including reflection heights and coefficients, are presented as a function of time of day. VLF long path propagation measurements, along with magnetometer and riometer data, are presented as supplementary information.

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Preface

The authors thank in particular Dr. Edward A. Lewis for valuable discussions on preparing this paper, SSgt Robert L. Cooley for data preparation, Mr. Royce C. Kahler of Barkley & Dexter Labs for help with the equipment that made the measurements possible, and Mr. Bjarne Ebbesen of the Danish Meteorological Institute for the outstanding operation at Qanaq, Greenland.

Appreciation is also extended to the Danish Commission for Scientific Research in Greenland for allowing these measurements to be conducted and to Jorgen Taagholt and V. Neble Jensen of the Danish Meteorological Institute's Ionospheric Laboratory for their continued cooperation in this program.

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VLF/LF Reflectivity of the Polar Ionosphere

1 May 1977 - 3 September 1977

1. INTRODUCTION

This paper provides a summary of high latitude ionospheric reflectivity, as observed by the USAF's high resolution VLF/LF ionosounder operating in northern Greenland.[1,2] As shown in Figure 1, the transmitter is located at Thule Air Base, Greenland (76° 33'N. Lat., 68° 40'W. Long), and the receiving site is 106 km north at the Danish Meteorological Institute's Ionospheric Observatory in Qanaq, Greenland (77° 24'N. Lat., 69° 20'W. Long., Geomagnetic Lat. 89° 06'N). The ionosounding transmissions consist of a series of extremely short (approximately 100 μsec) VLF pulses, precisely controlled in time, and radiated from a 130 meter vertical antenna. At the receiving site, orthogonal loop antennas are used to separate the two polarization components of the ionospherically reflected skywave signal. One antenna, oriented in the plane of propagation, is used to sense the groundwave and the "parallel" component of the downcoming skywave. The second loop, nulled on the groundwave, senses the "perpendicular" skywave component. The signal from each of the antennas is digitally averaged to improve the signal-to-noise ratio of the individual received waveforms before they are recorded on magnetic tape. An

(Received for publication 28 December 1977)

1. Lewis, E.A., Rasmussen, J.E., and Kossey, P.A. (1973) Measurements of ionospheric reflectivity from 6 to 35 kHz, J. Geophys. Res. 78:19.

2. Kossey, P.A., Rasmussen, J.E., and Lewis, E.A. (1974) VLF pulse ionosounder measurements of the reflection properties of the lower ionosphere, Akademie Verlag, COSPAR, July.

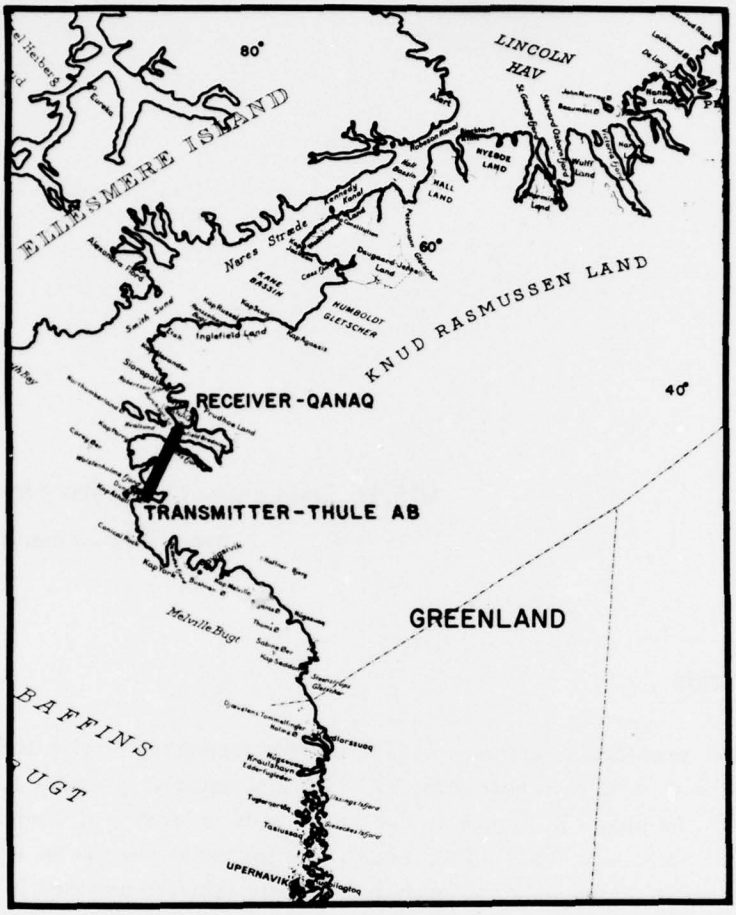


Figure 1. Geometry of the Propagation Path

example of the observed waveforms is given in Figure 2, where the "parallel" waveform (Figure 2a) consists of a groundwave propagated pulse, a quiet interval containing low level, off path groundwave reflections, followed by the first-hop parallel skywave component. The perpendicular waveform is shown in Figure 2b.

Ionospheric reflection parameters are derived by computer (AFGL's CDC 6600) processing of the ground and ionospherically reflected waveforms with allowance made for factors such as ground conductivity and antenna patterns (see Section 4).

Although the data are recorded about once per minute, for this paper the waveforms are averaged into two-hour time blocks with the exception of the three-dimensional waveform presentations (Section 2.2). The resulting information is presented in a weekly format (Figures 3 through 20) as described below.

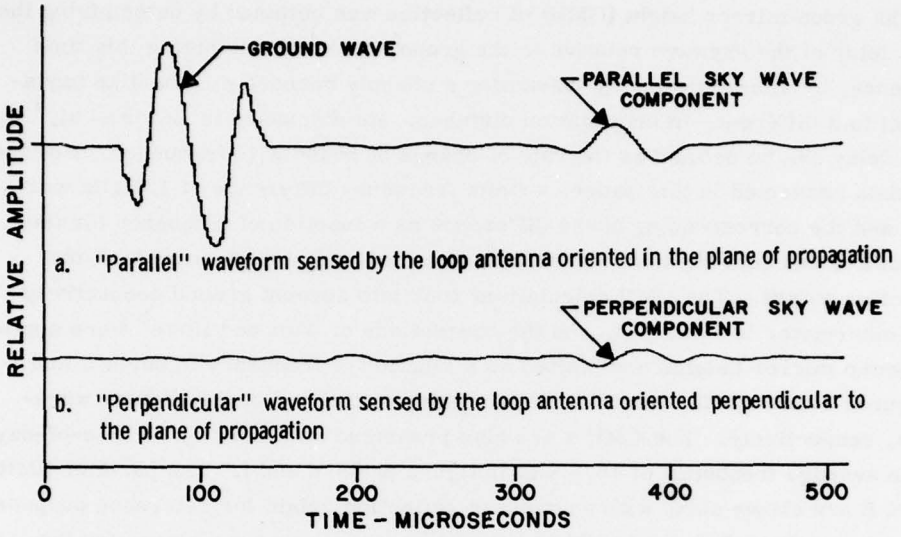


Figure 2. Example of the Observed Waveforms

2. OBSERVED WAVEFORMS

2.1 Weekly Example of Individual Waveforms

In part A of Figures 3 through 20 a set of averaged parallel and perpendicular waveforms is presented for the time block centered near local noon of the indicated day. Each of these waveforms is comprised of 256 digitally averaged points spaced 2 μsec apart. In part B of the figures, the groundwave Fourier amplitudes are shown as a function of frequency. Although the data presented in parts C through L of the figures are generally limited to frequencies in the first, or principal, lobe of the spectrum, information at higher frequencies can be used when sufficient signal-to-noise conditions exist. There is, however, a frequency range around each spectral null where insufficient signal exists for measurements.

2.2 Three-Dimensional Waveform Presentation

A three-dimensional display of the recorded $\parallel$ waveforms covering each weekly period is shown in Part R of each figure and the corresponding $\perp$ waveforms are shown in Part S. For these plots the data has been averaged into fifteen minute time blocks.

3. REFLECTION HEIGHTS

The group mirror height (GMH) of reflection was obtained by determining the group delay of the skywave relative to the groundwave and attributing this time difference, by simple geometry (assuming a sharply bounded mirror-like ionosphere) to a difference in propagation distance. As discussed in Lewis et al,[1] the group delay can be defined as the rate of change of phase with frequency. For the GMH data presented in this paper, a finite frequency difference of 1.0 kHz was used, and the corresponding phase difference as a function of frequency for the groundwave and both skywave signals was obtained by Fourier analysis of the respective pulses. The GMH calculations took into account ground conductivity (10^{-3} mho/meter is assumed), and the corrections of Wait and Howe[3] were applied.

Group mirror heights are plotted as a function of frequency in parts C and D of Figures 3 through 20, as obtained from the parallel and perpendicular waveforms, respectively. The GMH's are also presented as a function of time-of-day for the average frequency of 16.5 kHz in figure parts E and I. The parallel GMH's in part E are shown along with an average reflection height for reference purposes. Each point of the reference height is a weekly average, by time block, for the 7-day period indicated. The corresponding perpendicular GMH's, part I of the figures, are also shown with the weekly average for comparison. Part G gives the average, by time block, for the daily parallel GMH data of part E, and part K gives the corresponding perpendicular GMH averages from the daily data of part I.

4. REFLECTION COEFFICIENTS

Assuming that the ionosphere acts as a "mirror" at the GMH, plane wave reflection coefficients[4] were obtained by comparing the ratio of the skywave Fourier amplitude at a specific frequency to that of the groundwave, taking into account the antenna patterns, wave spreading, earth curvature, ground conductivity, path lengths, and antenna patterns including ground image effects.

The reflection coefficient $_{||}R_{||}$ was obtained from analysis of the parallel skywave component and is plotted as a function of frequency in part C of Figures 3 through 20. The $_{||}R_{||}$ coefficient for 16 kHz is plotted as a function of time-of-day in part F along with the average of the indicated week for reference purposes. From the perpendicular skywave pulse, the coefficient $_{||}R_{\perp}$ was obtained and appears

3. Wait, J.R., and Howe, H.H. (1956) Amplitude and Phase Curves for Ground-Wave Propagation in the Band 200 Cycles per Second to 500 Kilocycles, Nat. Bur. Stand. U.S. Circ. No. 574.

4. Budden, K.G. (9161) Radio Waves in the Ionosphere, p. 85, Cambridge University Press, London.

as a function of frequency in part D. The 16 kHz $||R_{\perp}$ is shown along with its reference in part J. Parts H and L present the average, by time block, of the daily $||R_{||}$ and $||R_{\perp}$ data presented in parts F and J, respectively.

For certain coefficient data points, plotted as asterisks (*), the reflection coefficient appears without a corresponding GMH. For these particular data, only the skywave-groundwave ratios could be obtained as the skywaves were too weak to provide reliable group delay information. The reflection coefficients were therefore estimated using a nominal GMH of 80 km in the calculations. These estimated coefficient values are included in the averages presented in parts H and L, but the assumed heights are not used in the GMH averages shown in parts G and K.

5. SUPPLEMENTARY INFORMATION

For purposes of comparison and interpretation, certain supplementary data are presented. Part M of the figures shows the magnitude of the horizontal component of the polar magnetic field as recorded on a three axis fluxgate magnetometer and part N presents 30-MHz riometer data, an indicator of D-region particle precipitation. These supplementary data were recorded at 30-sec intervals by RADC/EEP at Thule AB; the curves represent the average of 10-minute periods. The solar zenith angle is given in part O of Figures 3 through 20 for the indicated mid-week date.

6. IONOSPHERIC DISTURBANCE DATA

It is noted that during this period one minor energetic particle event occurred beginning on DAY 207 (27 July). This disturbance produced less than 0.5 dB of absorption on the 30 MHz riometer; however, its effects are clearly seen in the VLF/LF reflectivity data (Figure 15). There was a drop in the apparent reflection height to about 70 km, followed by a gradual return to normal conditions over the next 3 days.

7. ADDITIONAL COMMENTS

This report is one of a series.[5, 6, 7, 8, 9, 10, 11, 12] Comments and suggestions for improving its usefulness should be addressed to the Propagation Branch (EEP), Electromagnetic Sciences Division, Deputy for Electronic Technology (RADC/EEP), Hanscom AFB, Massachusetts 01731.

(Because of the large number of references cited above, they will not be listed here. See Reference Page 85 for References 5 through 12.)

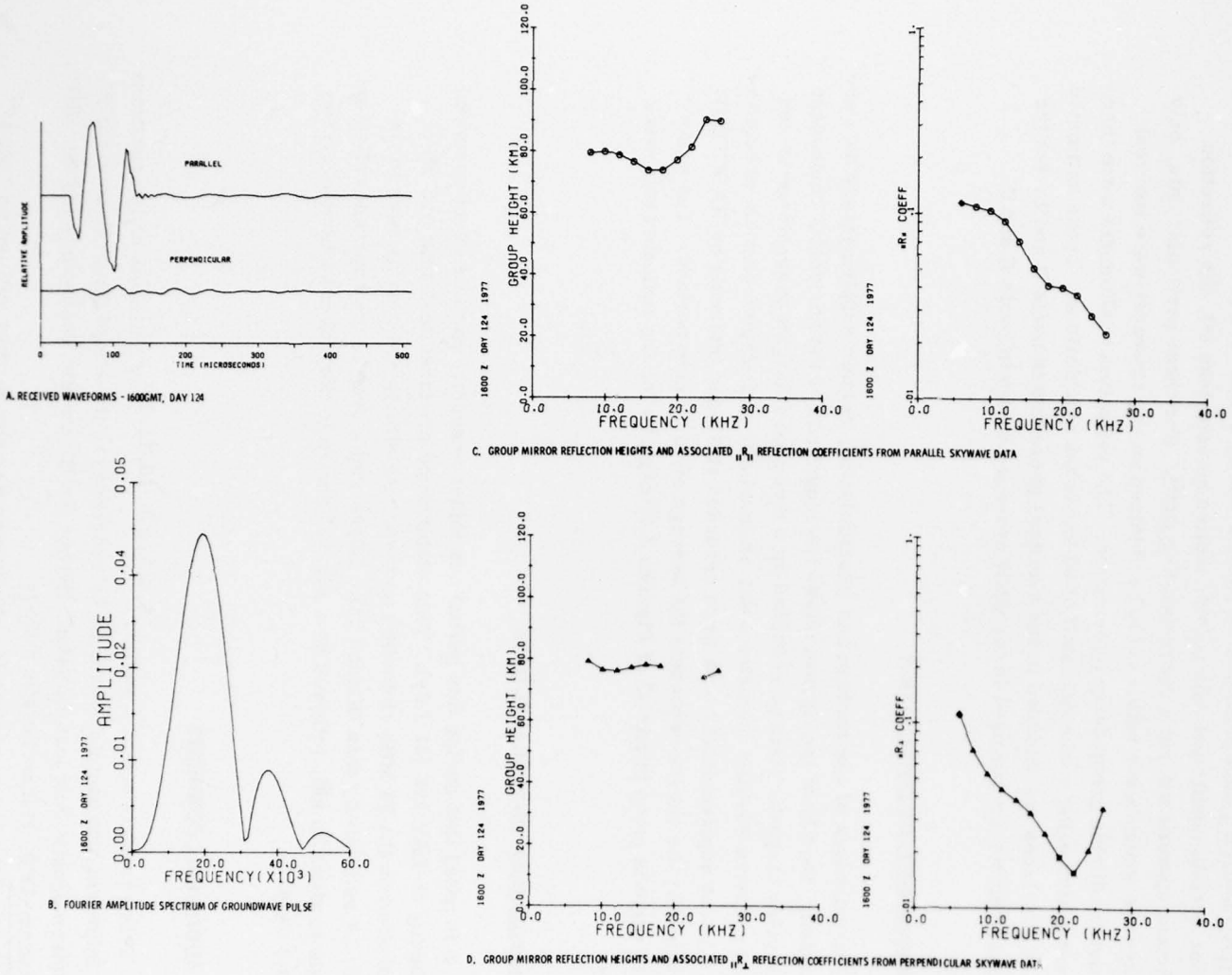


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 121 (1 May) — DAY 127 (7 May) 1977

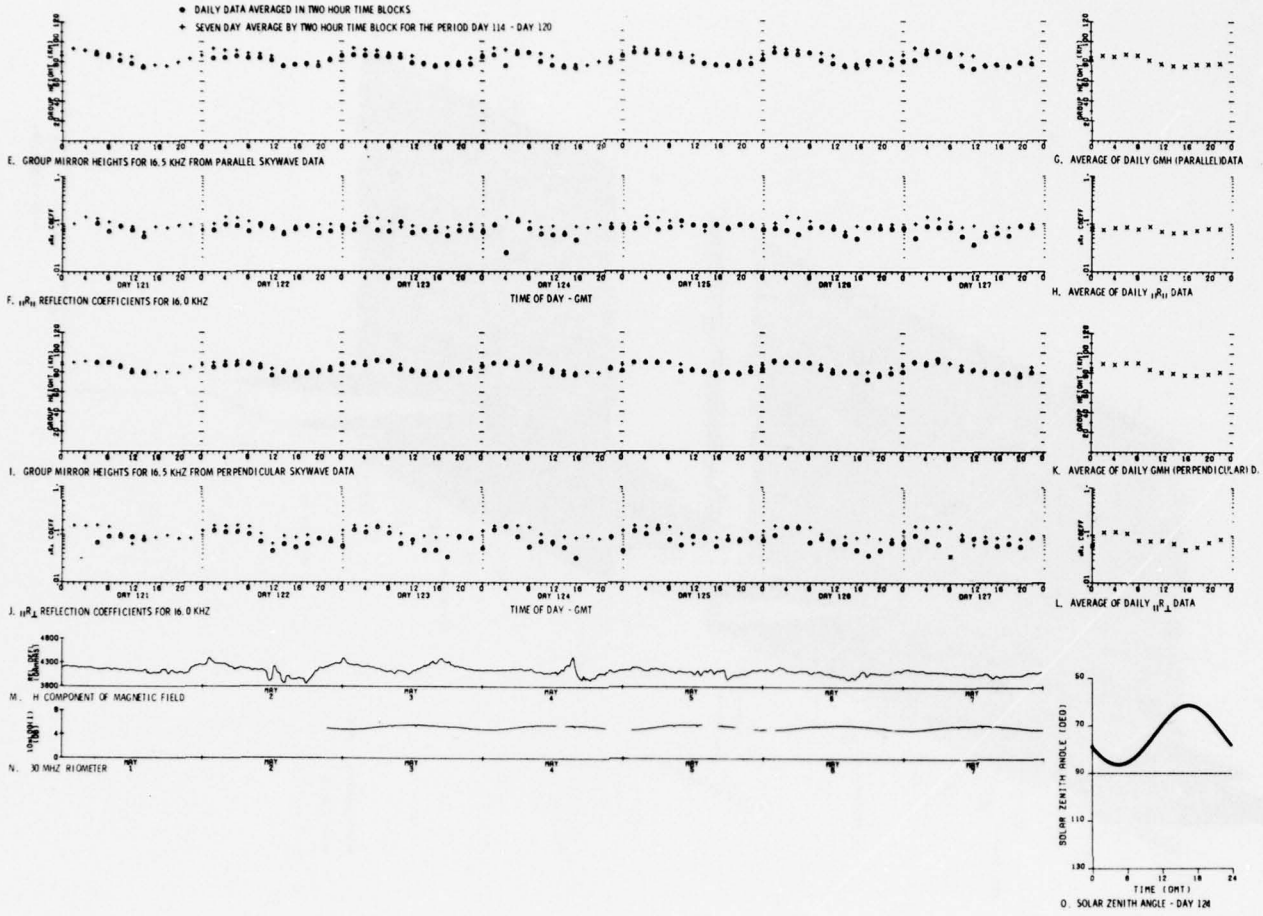


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 121 (1 May) — DAY 127 (7 May) 1977 (Cont)

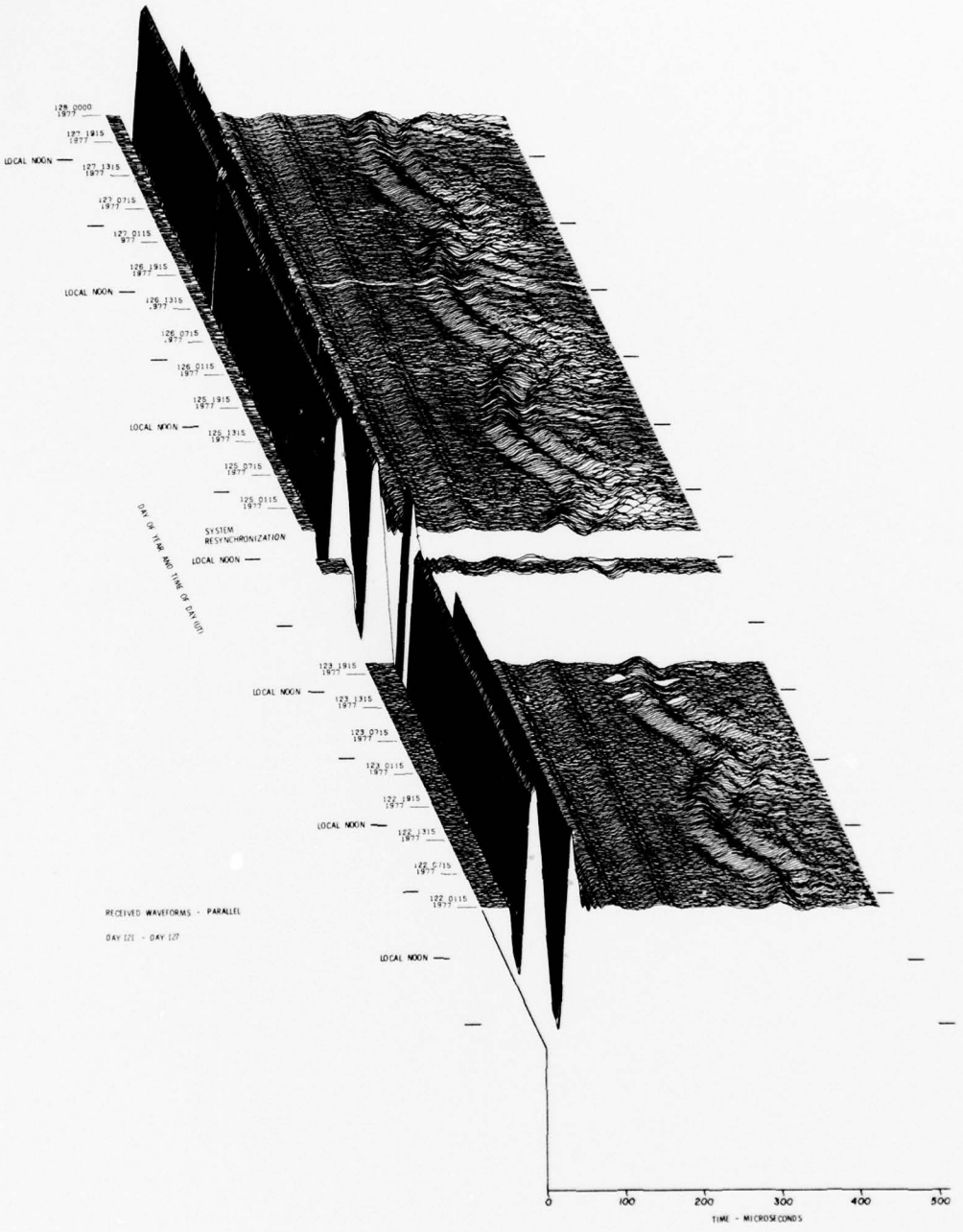


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 121 (1 May) – DAY 127 (7 May) 1977 (Cont)
Part R. || Waveform Display

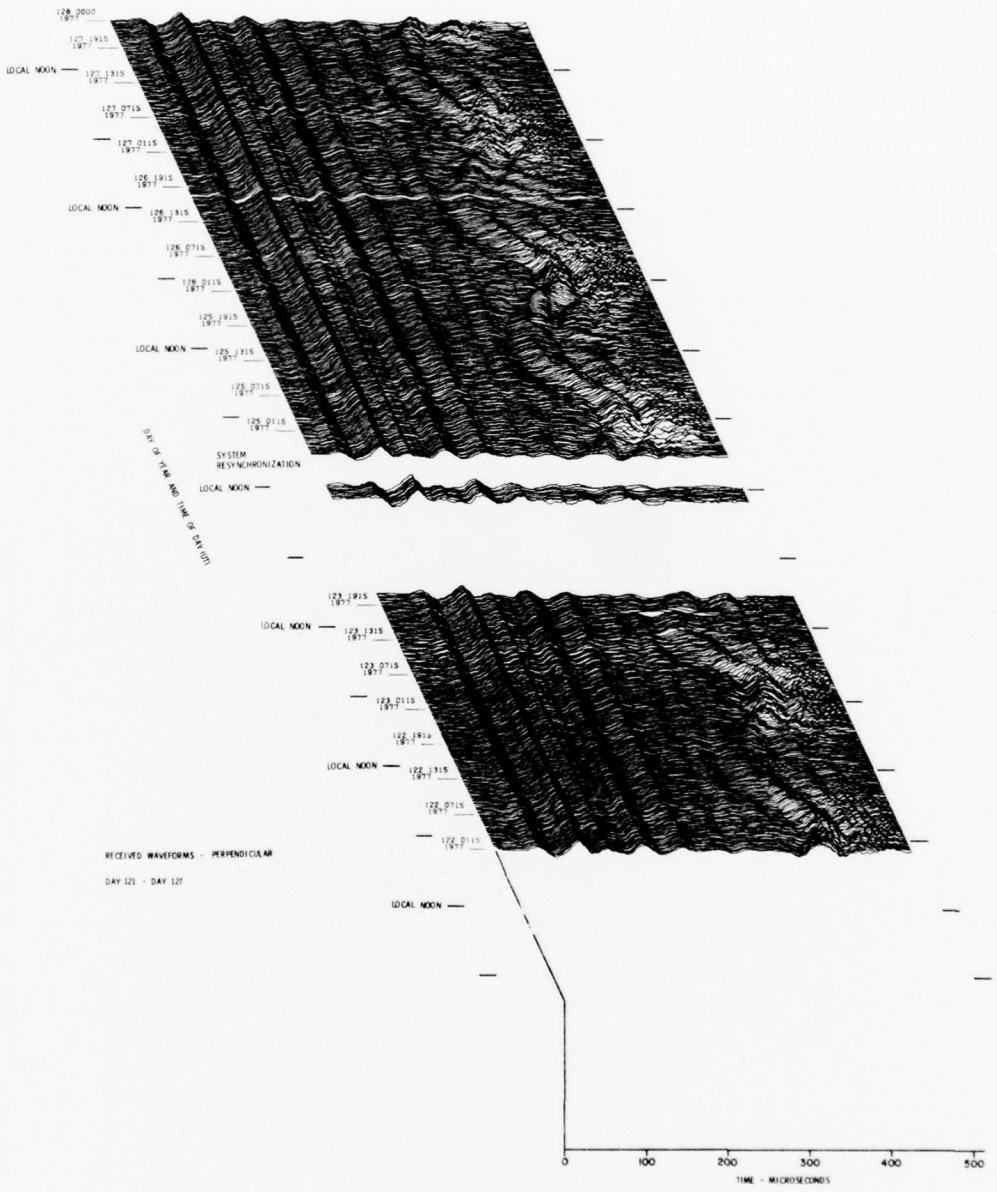
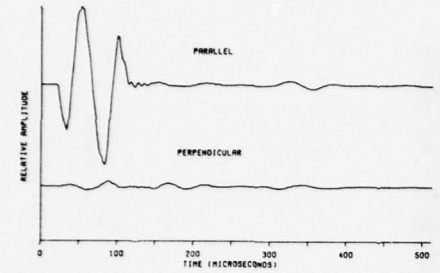
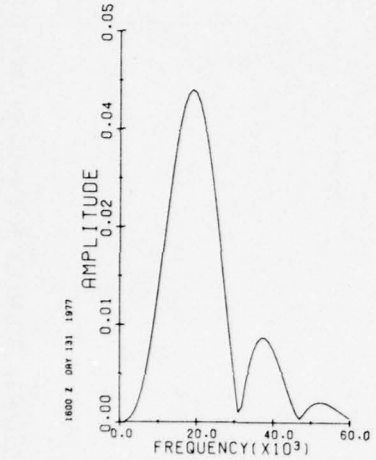


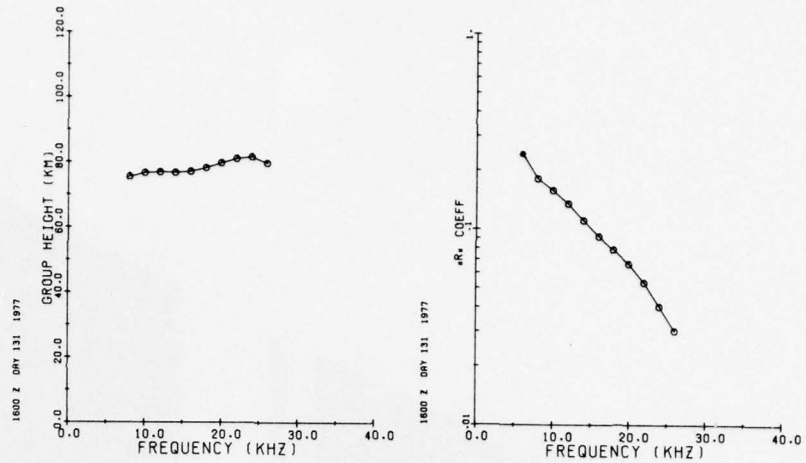
Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 121 (1 May) — DAY 127 (7 May) 1977 (Cont)
Part S. ⊥ Waveform Display



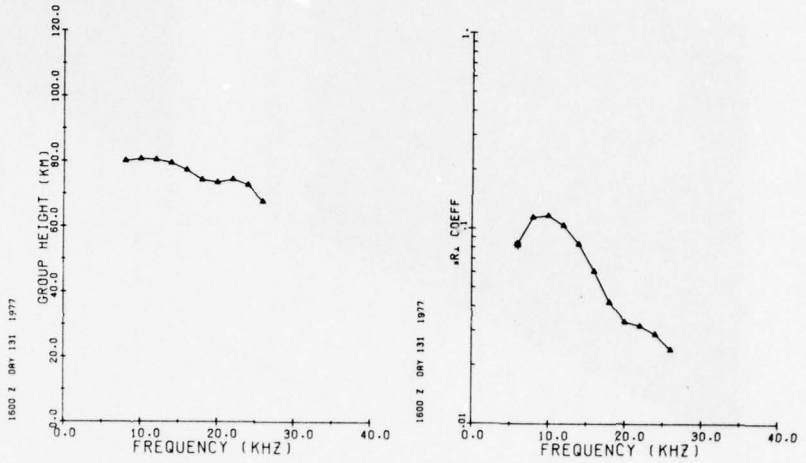
A. RECEIVED WAVEFORMS - 1600GMT, DAY 131



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE



C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $|R_{\parallel}|$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $|R_{\perp}|$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 128 (8 May) — DAY 134 (14 May) 1977

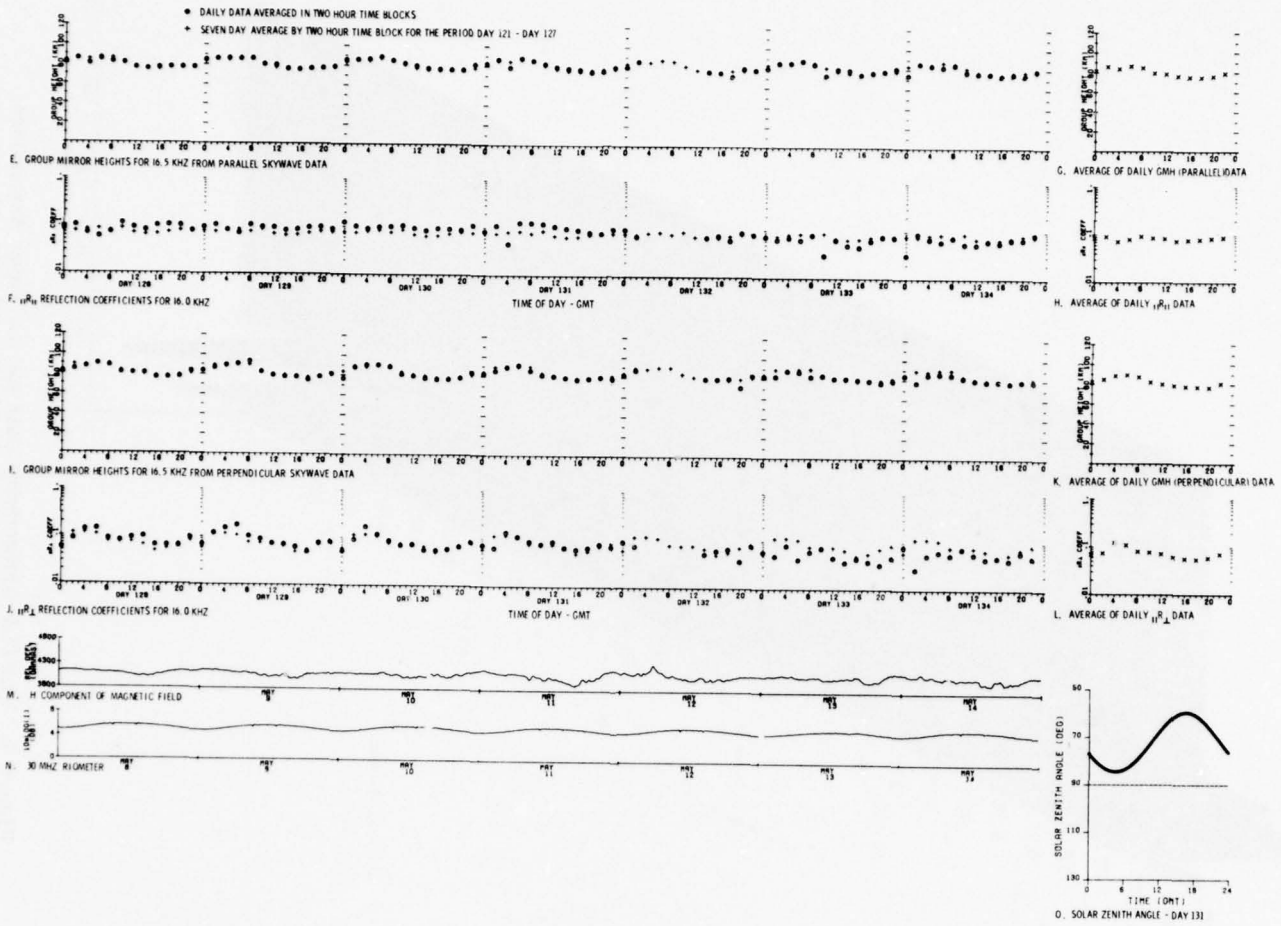


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 128 (8 May) — DAY 134 (14 May) 1977 (Cont)

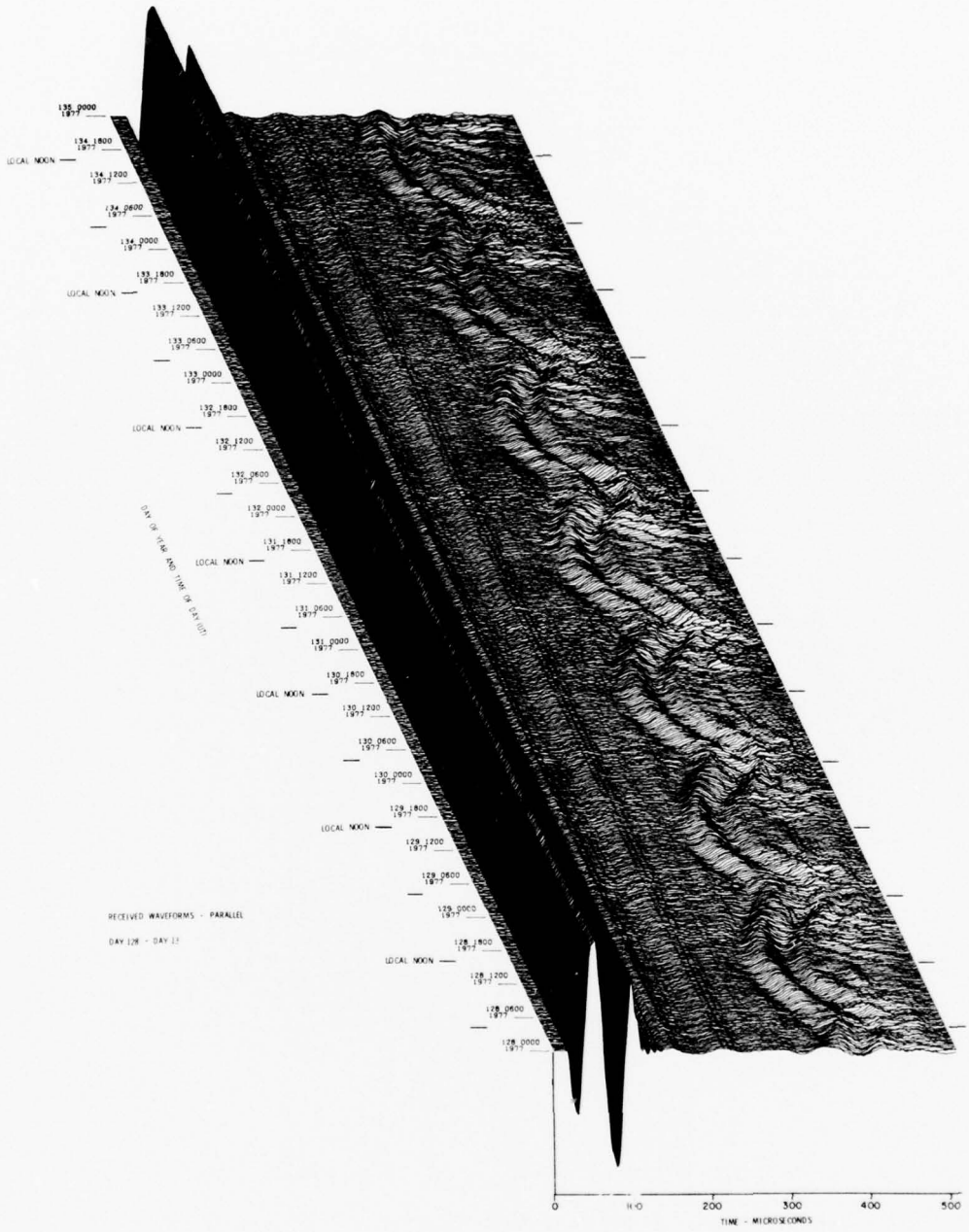


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 128 (8 May) – DAY 134 (14 May) 1977 (Cont)
Part R. || Waveform Display

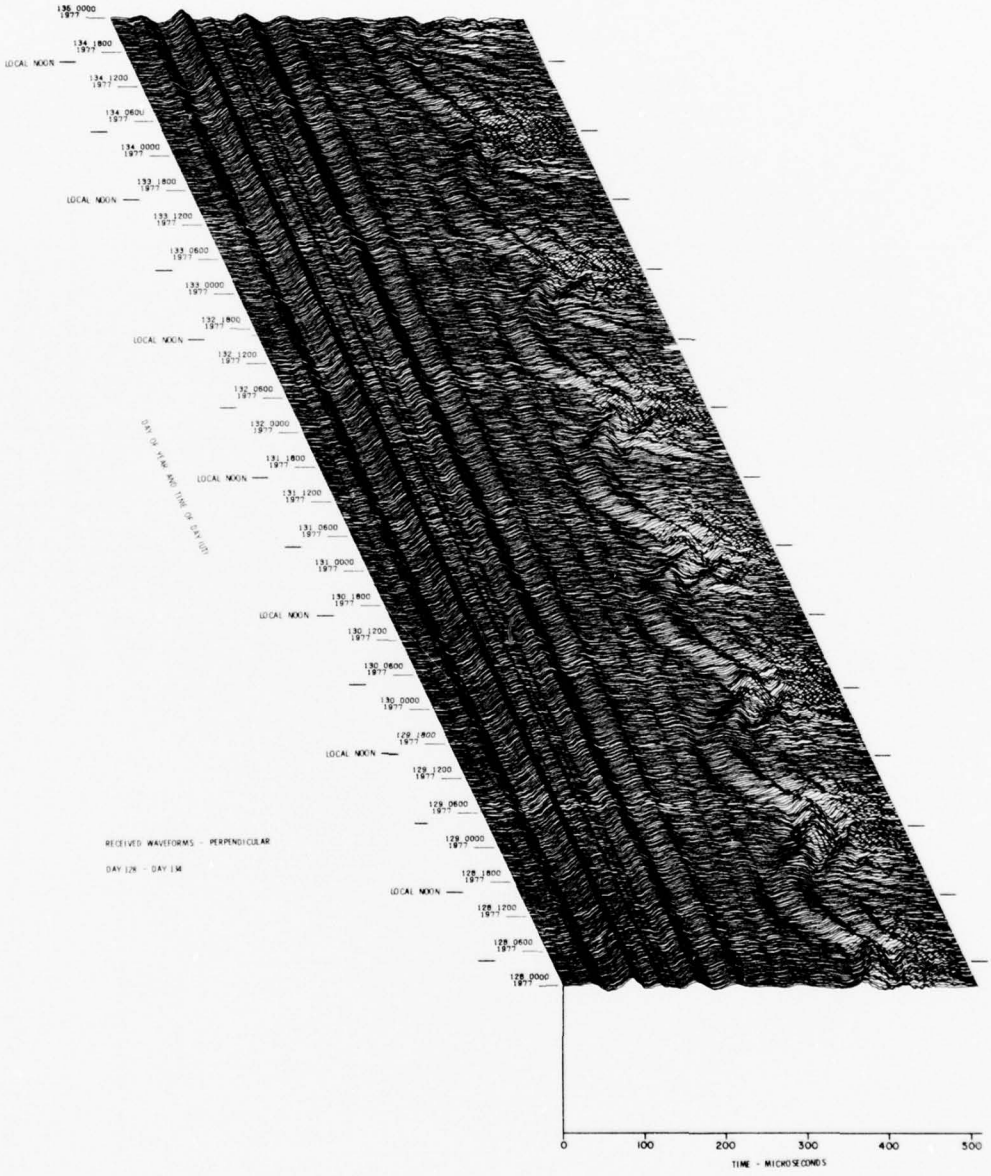


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 128 (8 May) – DAY 134 (14 May) 1977 (Cont)
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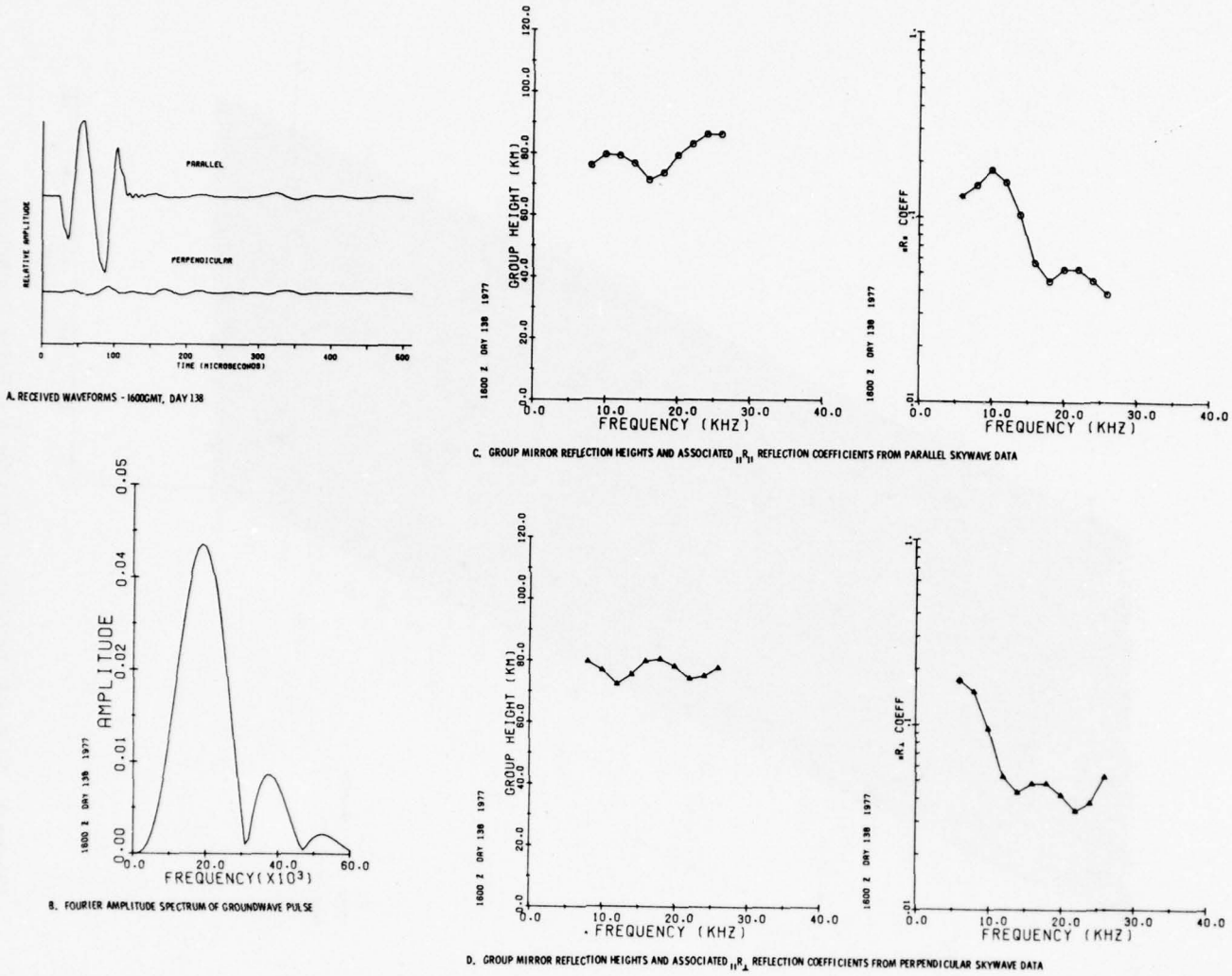


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 135 (15 May) — DAY 141 (21 May) 1977

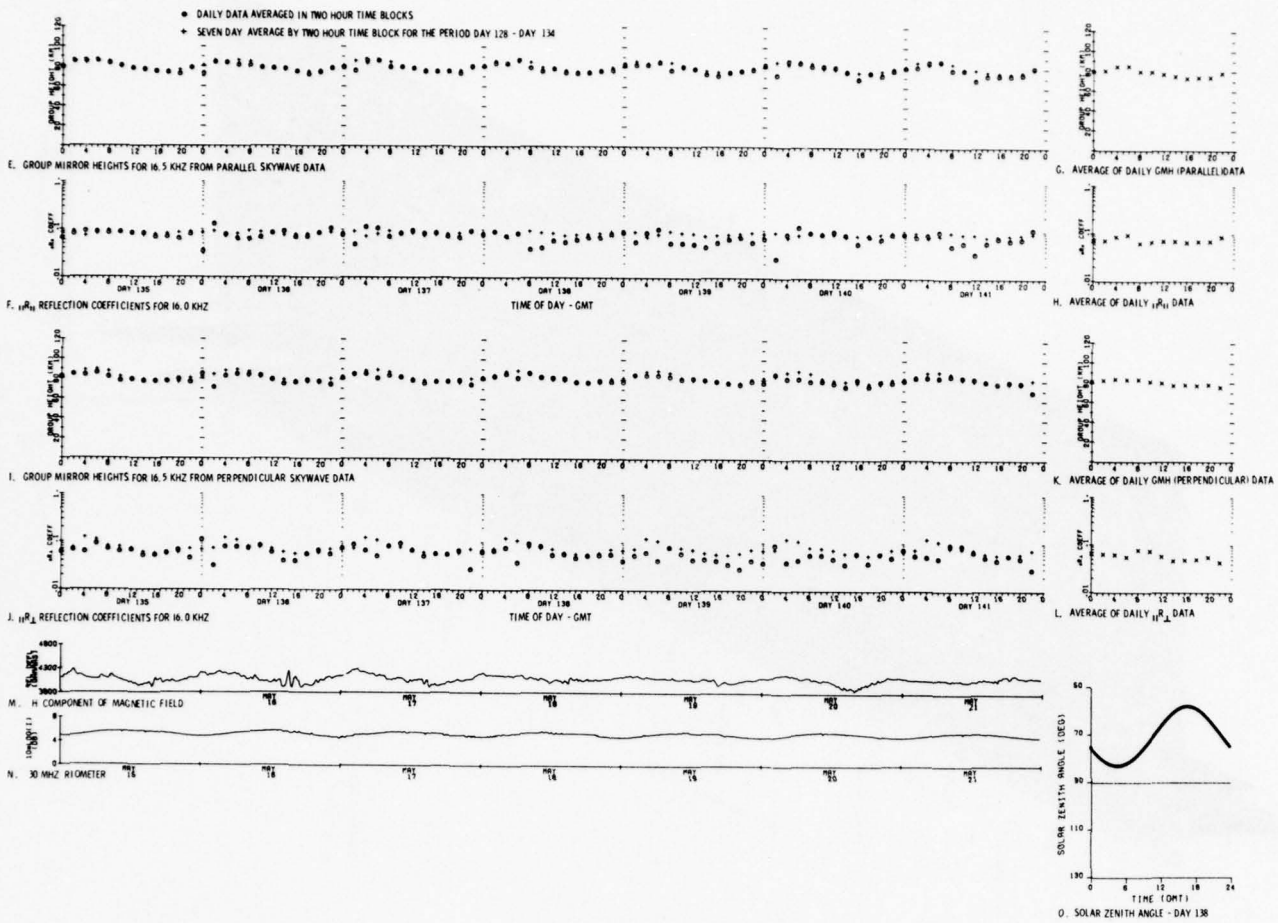


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 135 (15 May) — DAY 141 (21 May) 1977 (Cont)

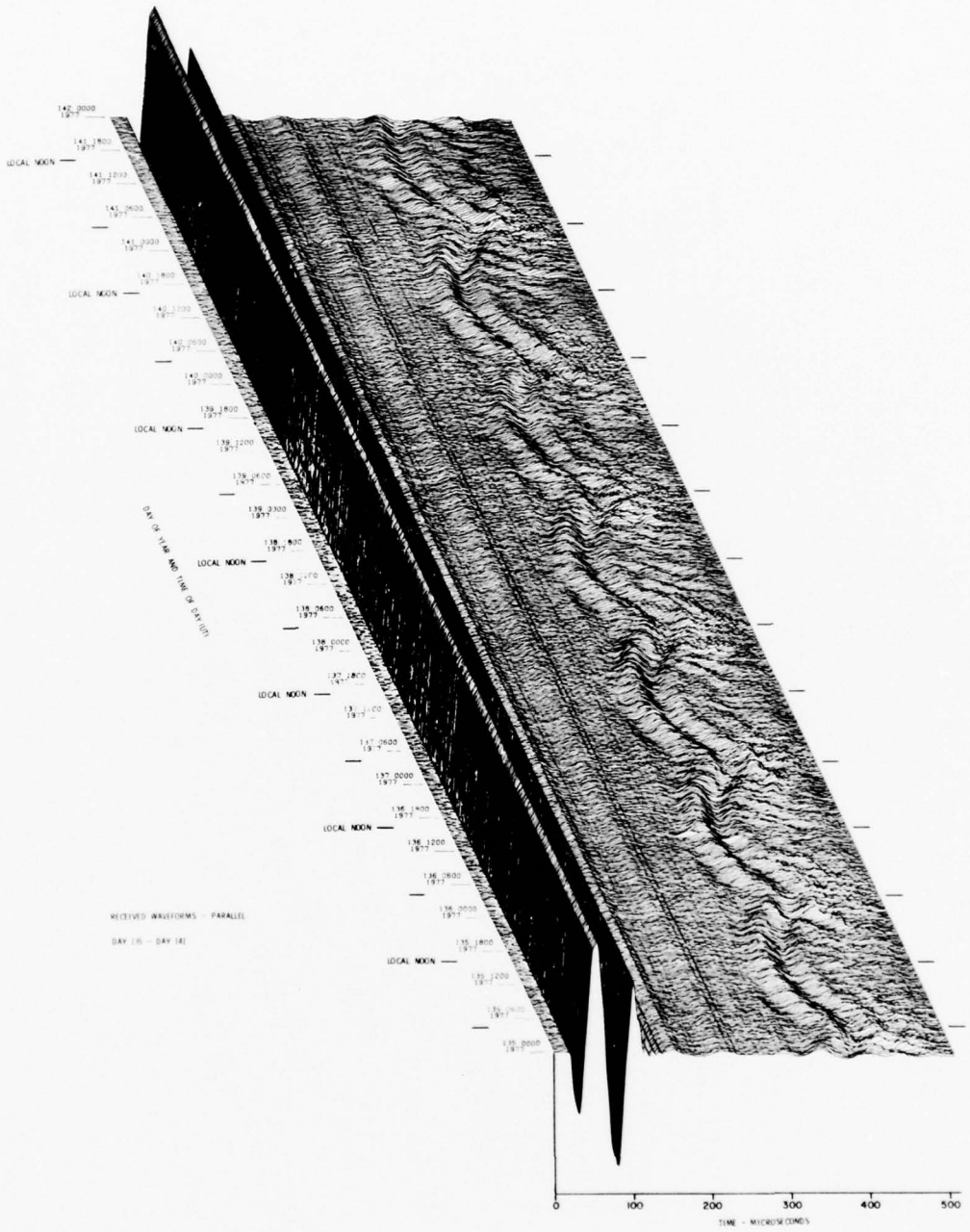


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 135 (15 May) – DAY 141 (21 May) 1977 (Cont)
Part R. || Waveform Display

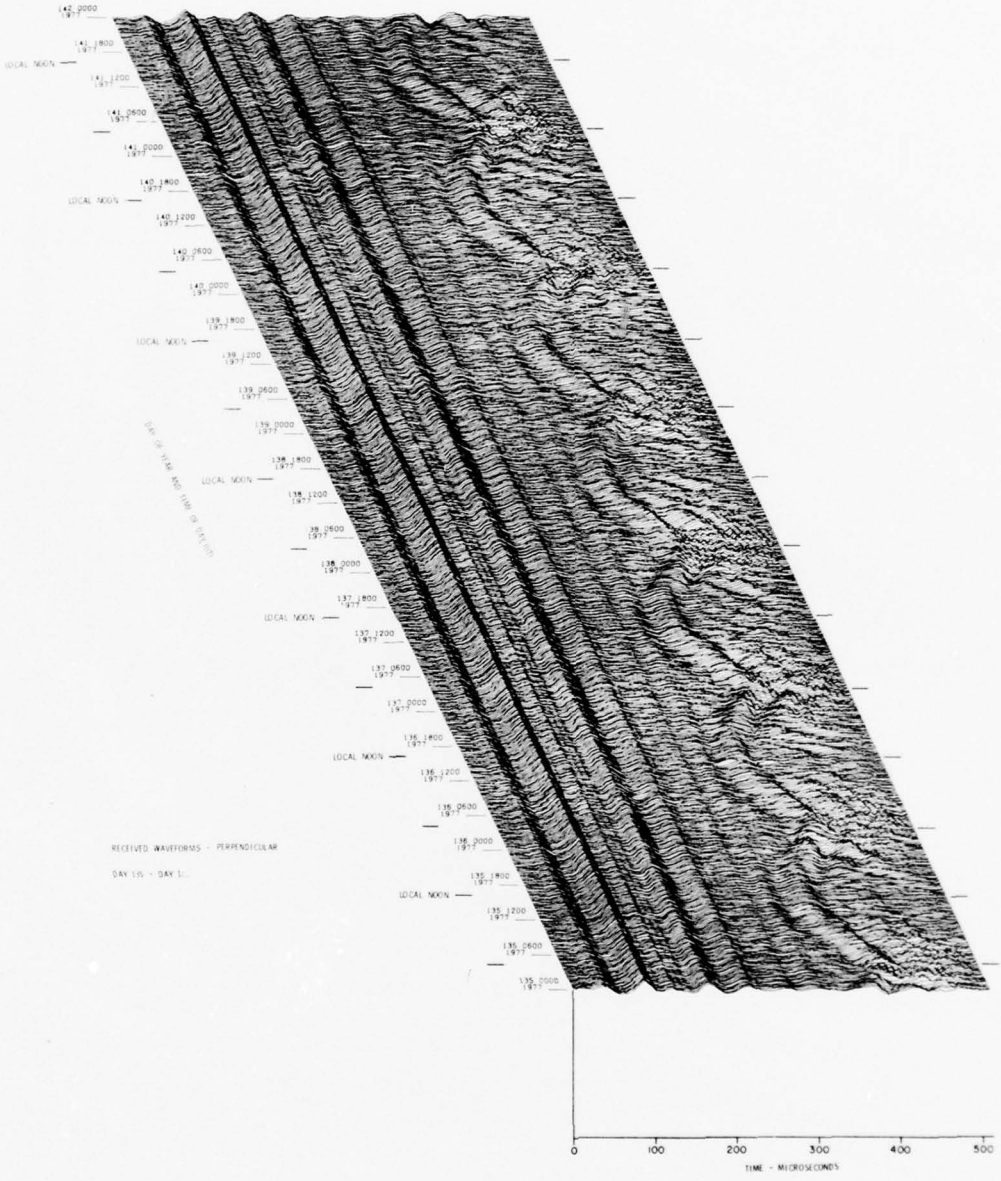
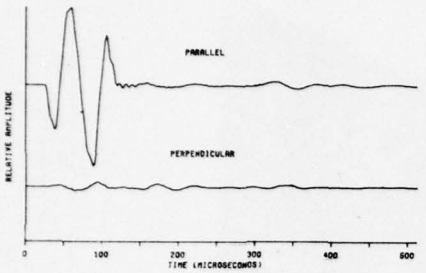
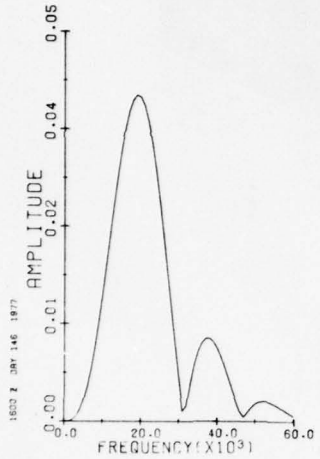


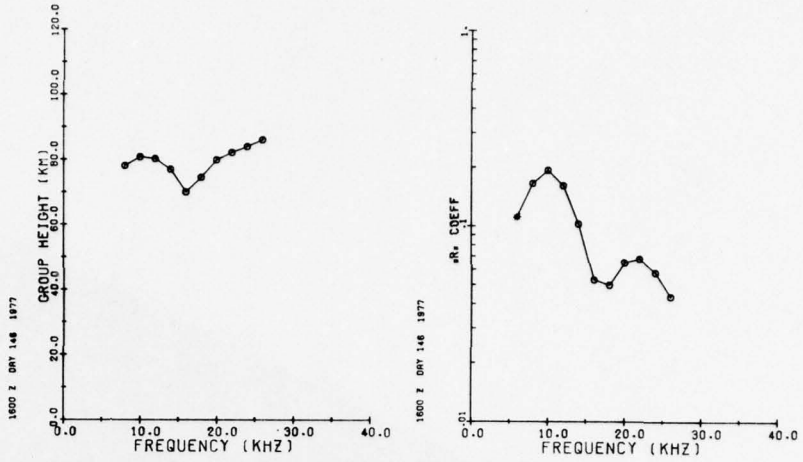
Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 135 (15 May) – DAY 141 (21 May) 1977 (Cont)
Part S. ⊥ Waveform Display



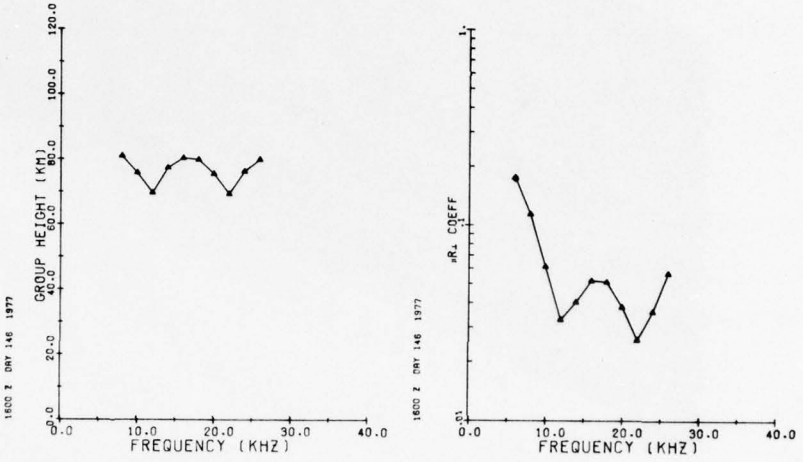
A. RECEIVED WAVEFORMS - 1600GMT, DAY 146



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE



C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\parallel}$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\perp}$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 142 (22 May) — DAY 148 (28 May) 1977

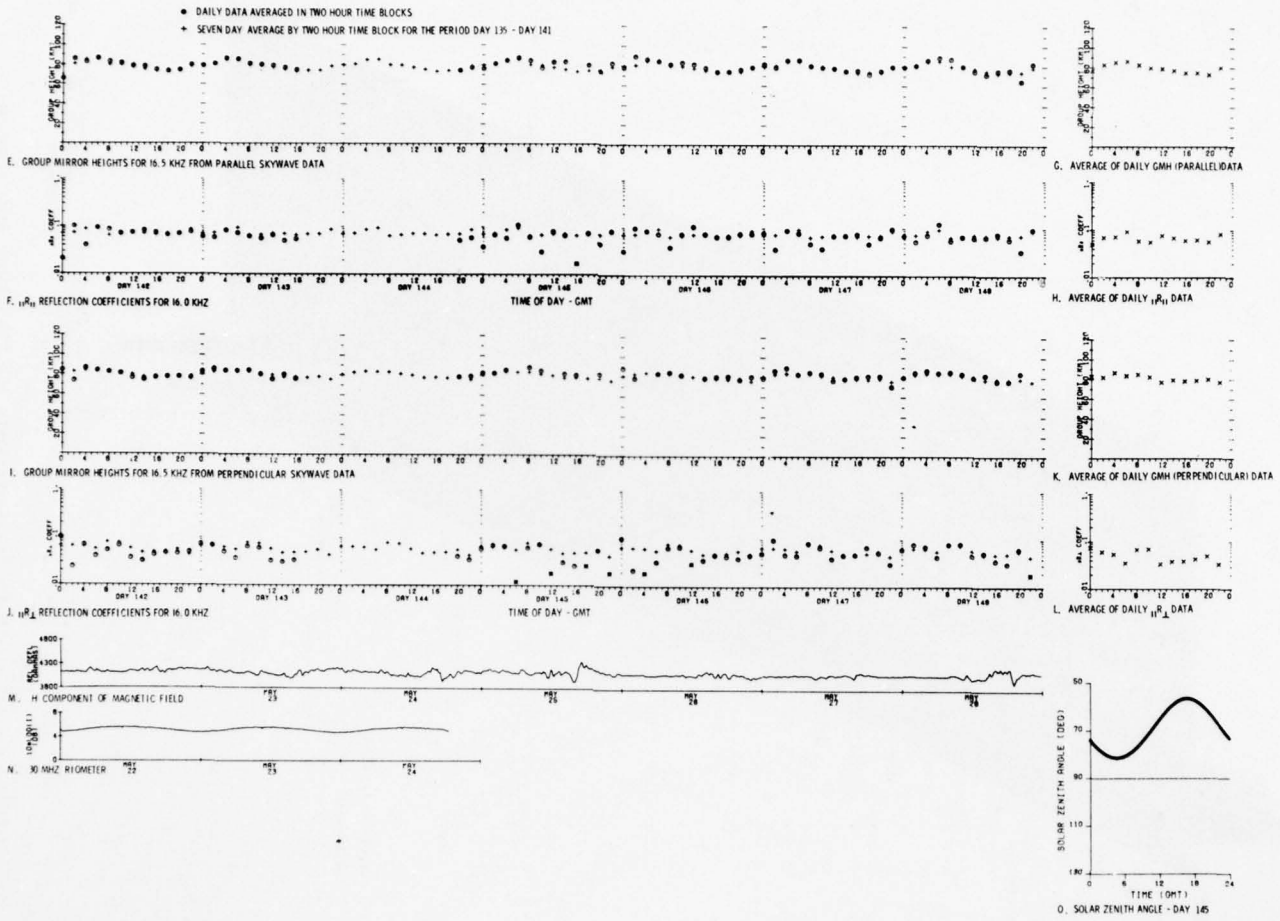


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 142 (22 May) — DAY 148 (28 May) 1977 (Cont)

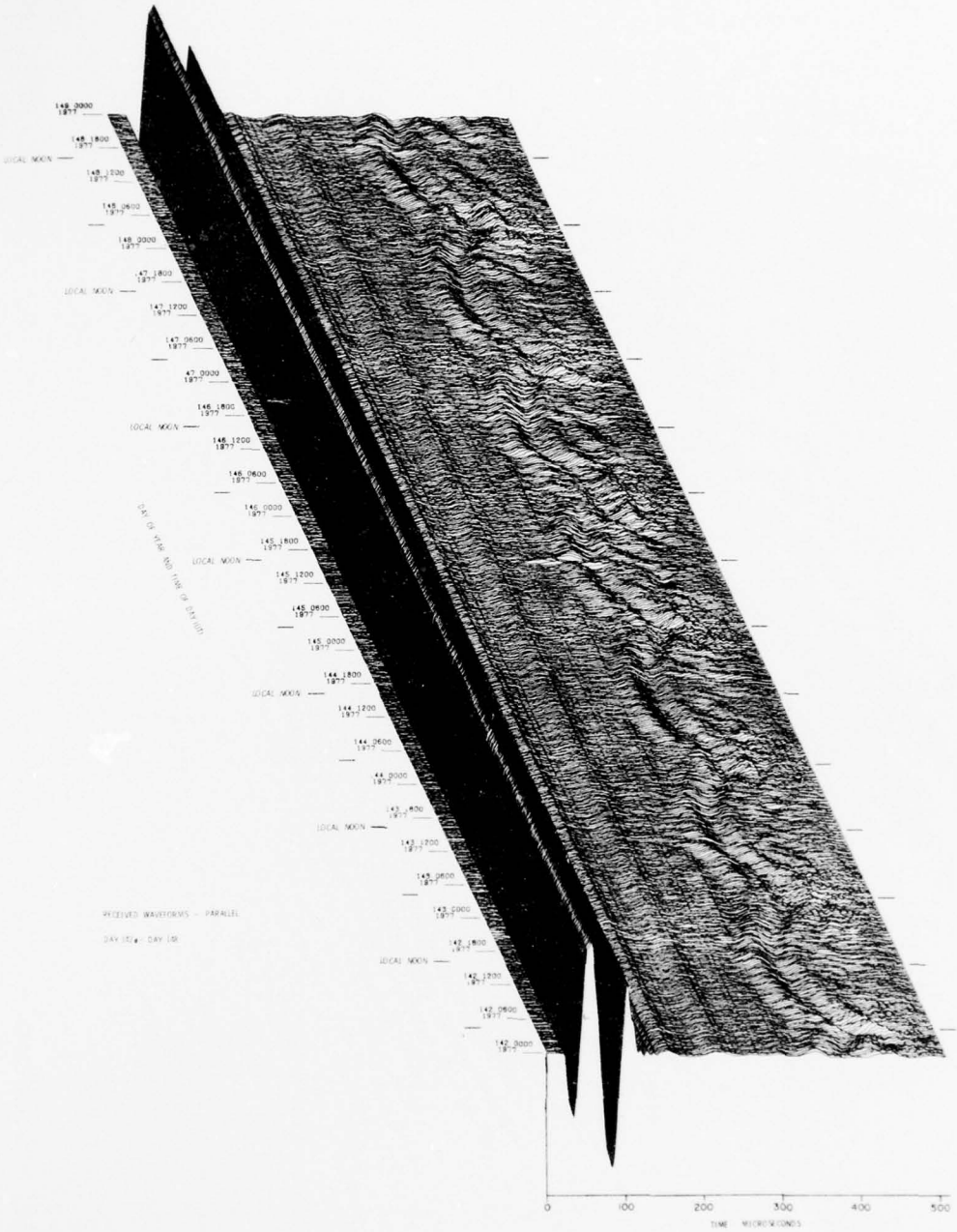


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 142 (22 May) — DAY 148 (28 May) 1977 (Cont)
Part R. ⏸ Waveform Display

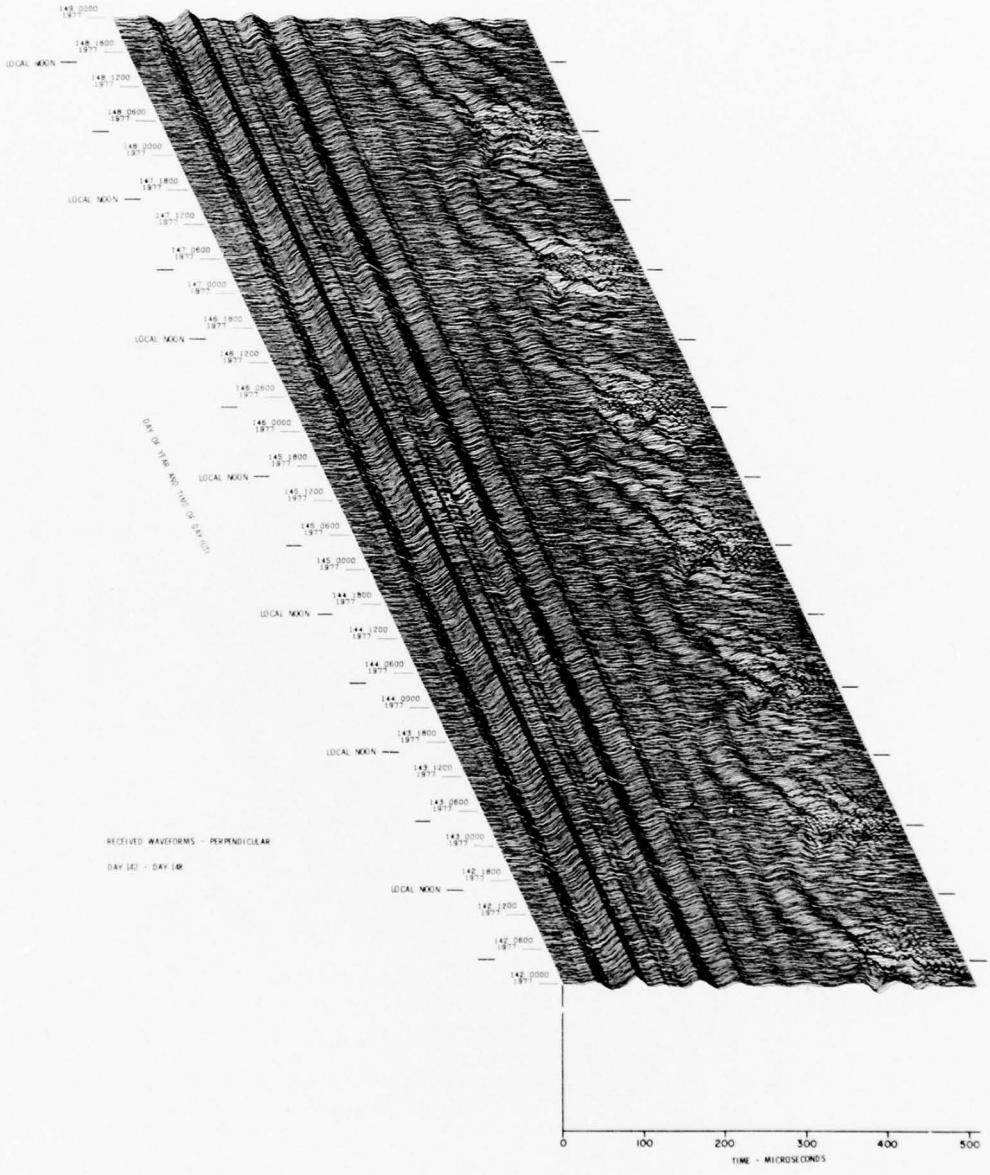
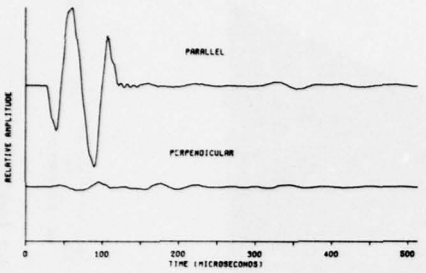
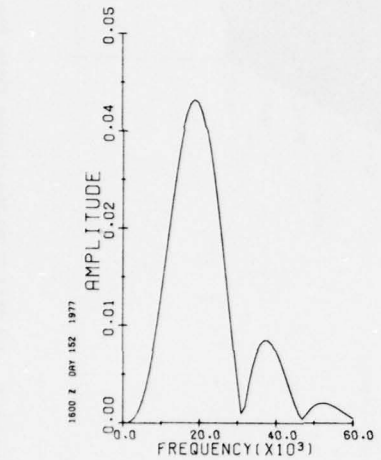


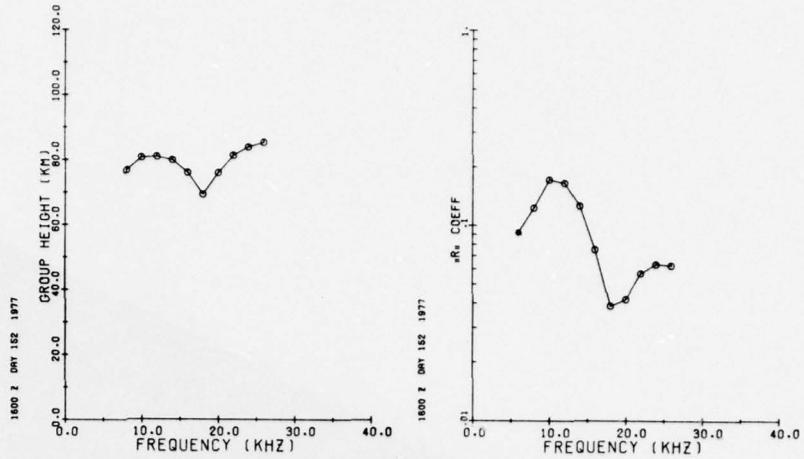
Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 142 (22 May) – DAY 148 (28 May) 1977 (Cont)
Part S. ⊥ Waveform Display



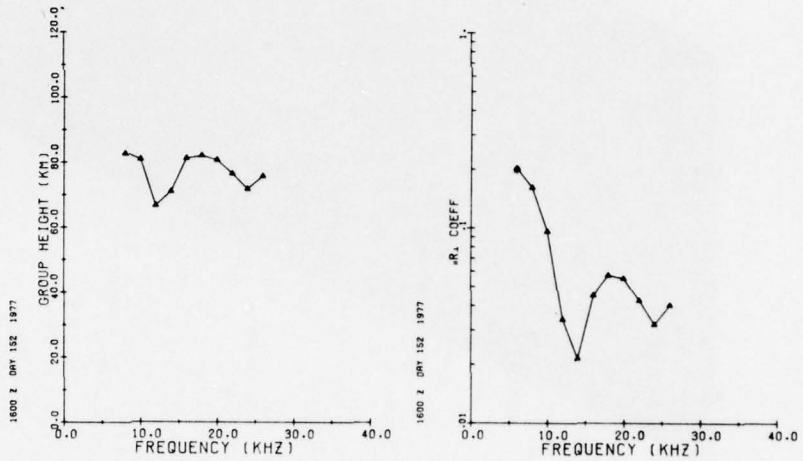
A. RECEIVED WAVEFORMS - 1600GMT, DAY 152



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE



C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\parallel}$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\perp}$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 149 (29 May) – DAY 155 (4 Jun) 1977

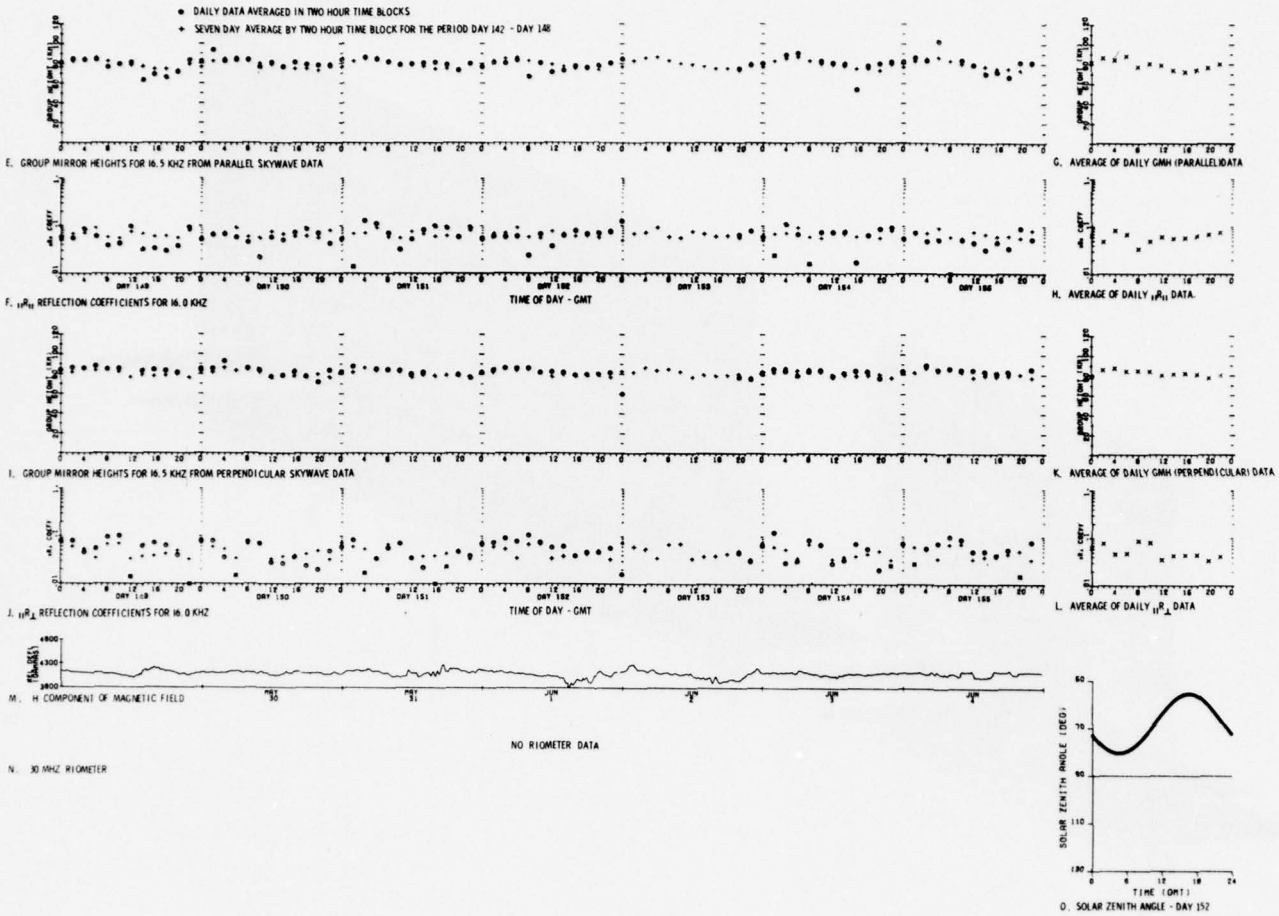


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 149 (29 May) — DAY 155 (4 Jun) 1977 (Cont)

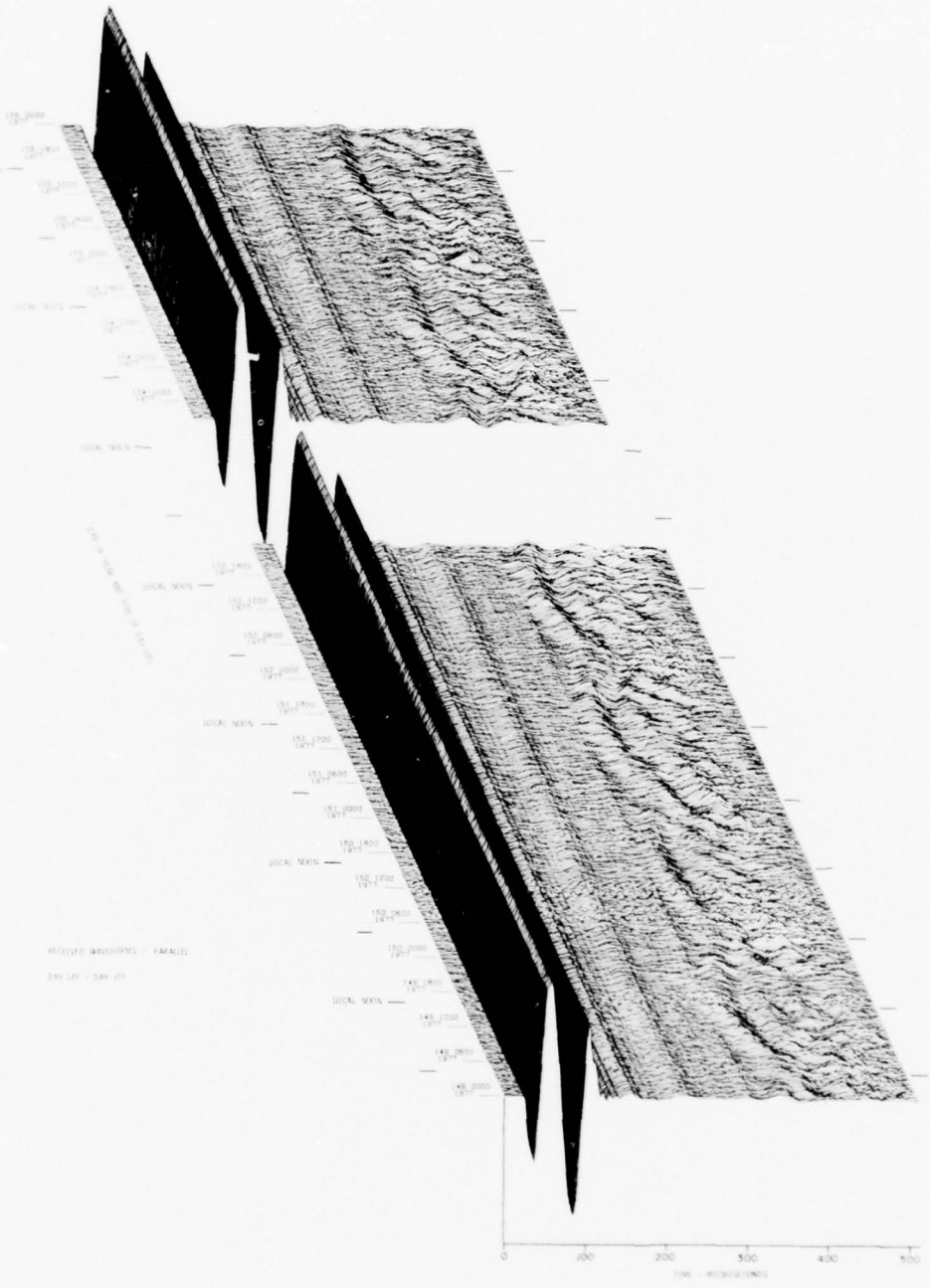


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 149 (29 May) – DAY 155 (4 Jun) 1977 (Cont)
Part R. ∥ Waveform Display

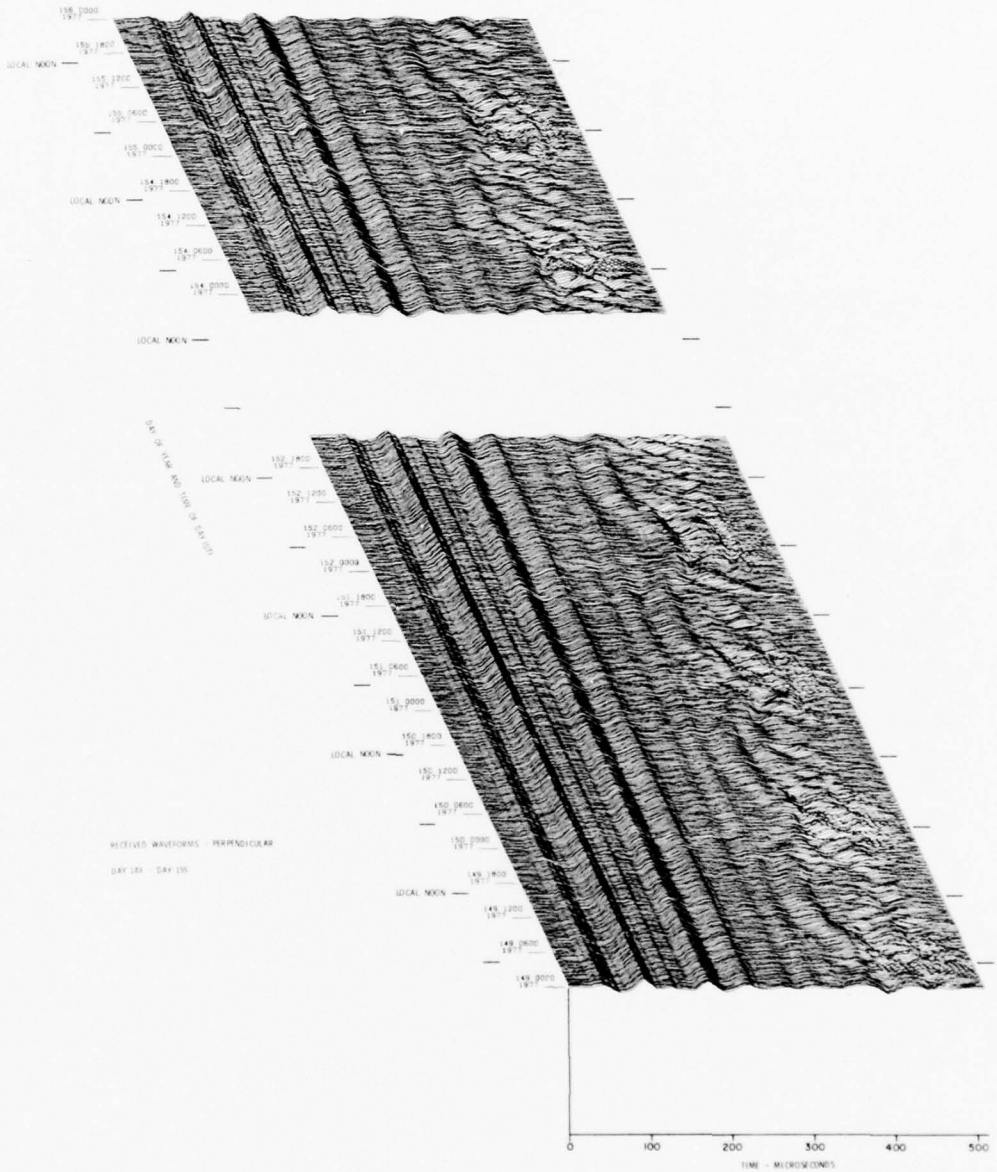
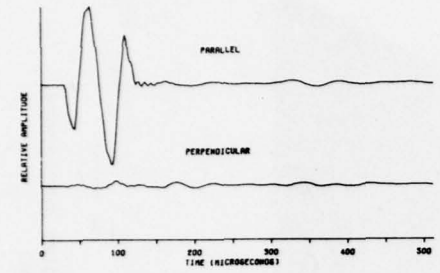
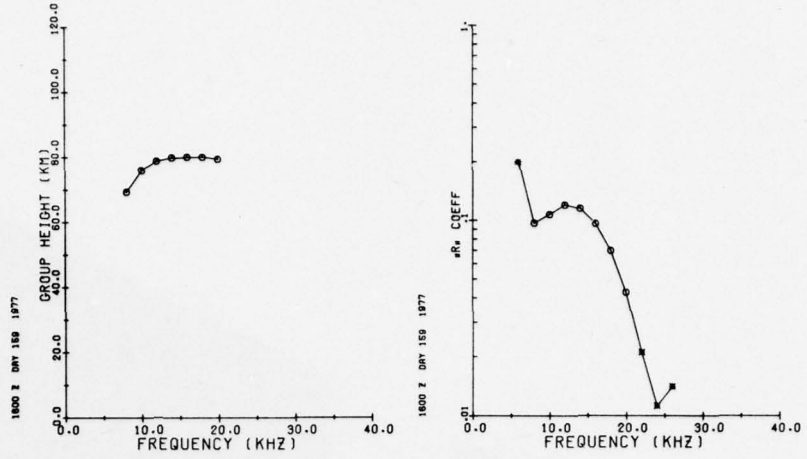


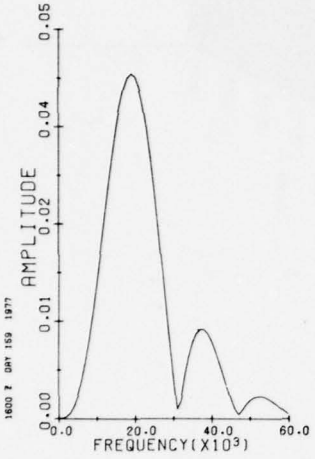
Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 149 (29 May) – DAY 155 (4 Jun) 1977 (Cont)
Part S. ⊥ Waveform Display



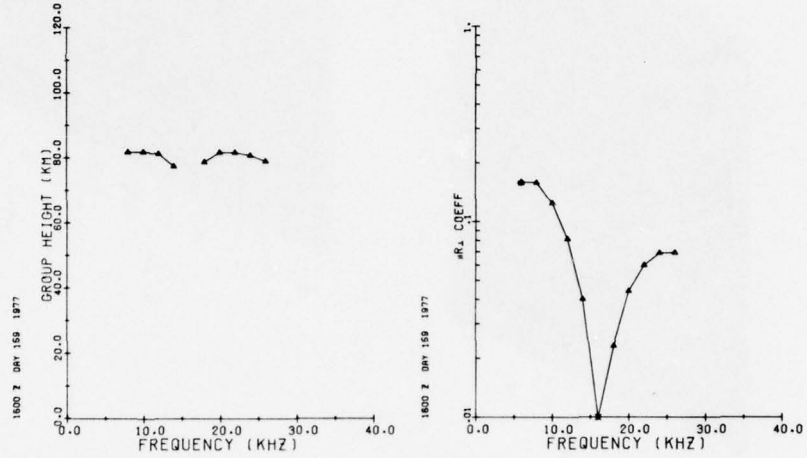
A. RECEIVED WAVEFORMS - 1600GMT, DAY 159



C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\parallel}$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\perp}R_{\perp}$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 156 (5 Jun) — DAY 162 (11 Jun) 1977

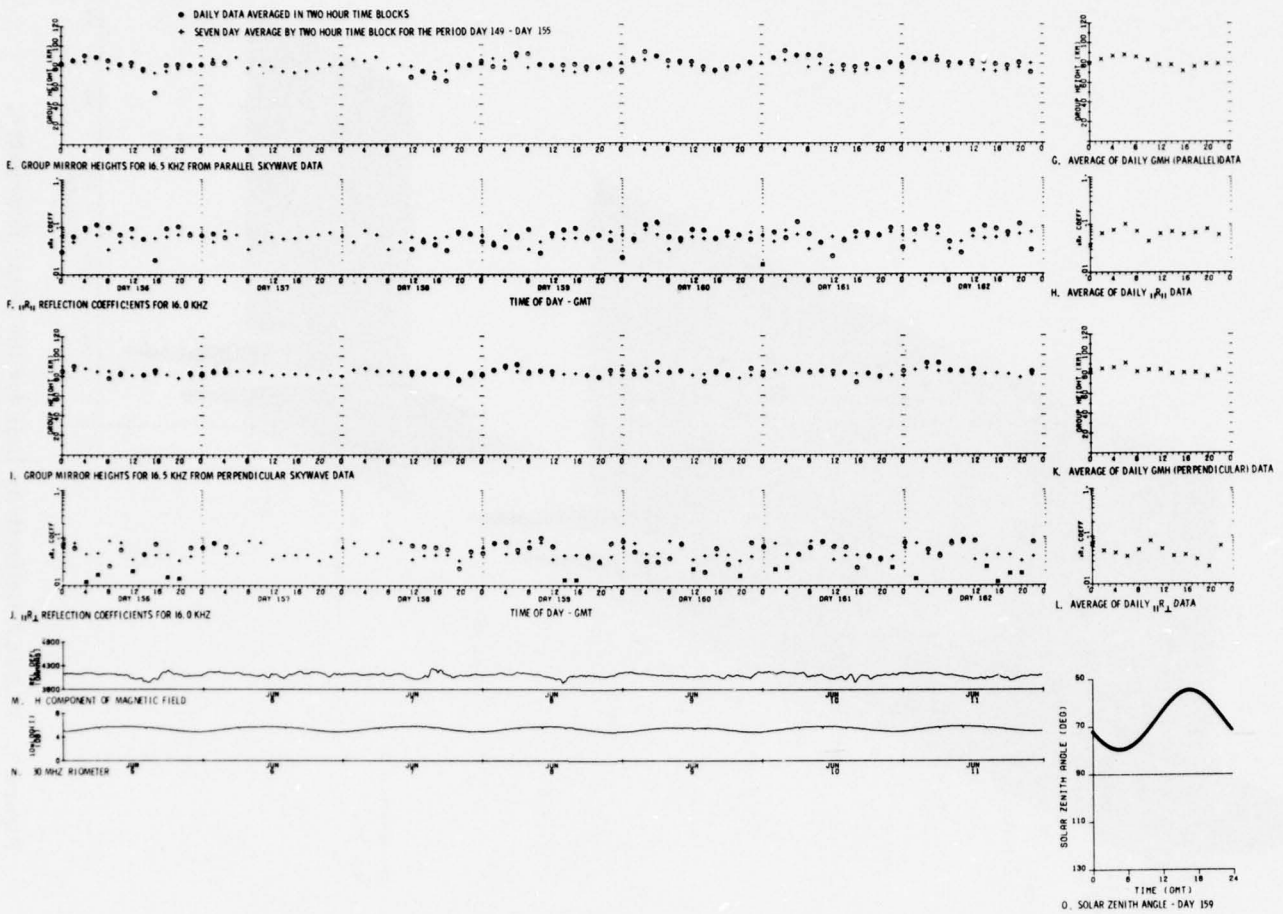


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 156 (5 Jun) — DAY 162 (11 Jun) 1977 (Cont)

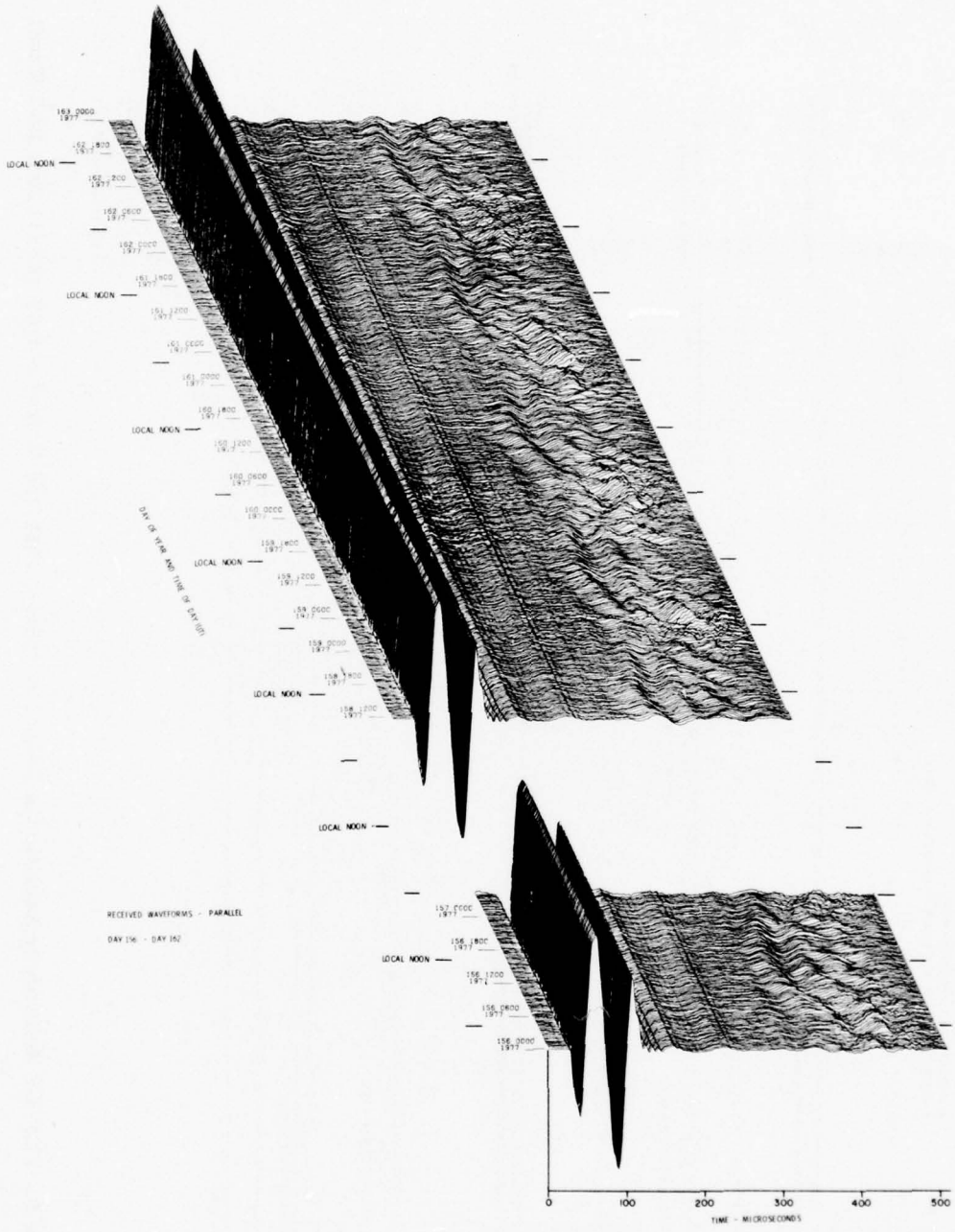


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 156 (5 Jun) – DAY 162 (11 Jun) 1977 (Cont)
Part R. II Waveform Display

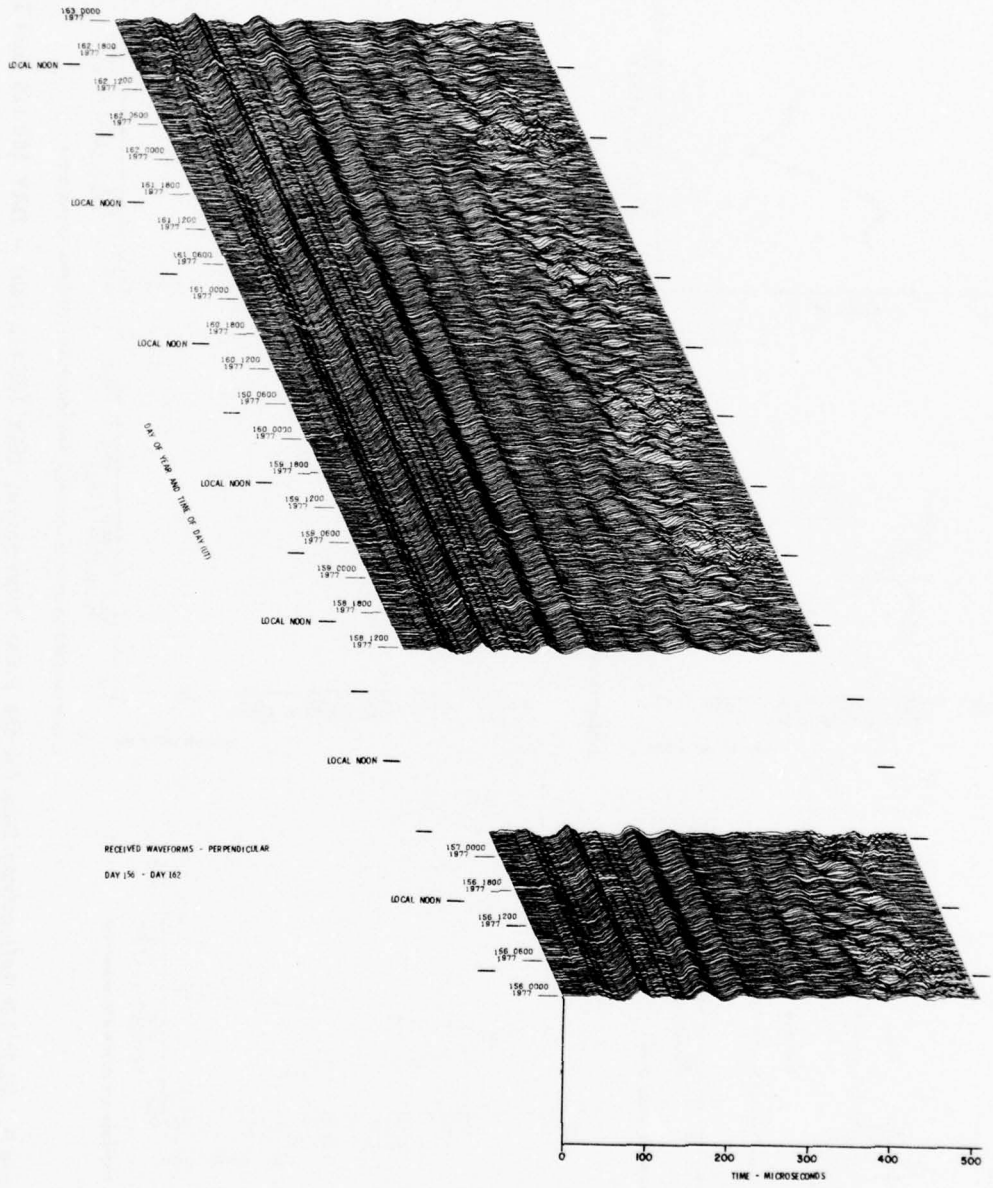


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 156 (5 Jun) – DAY 162 (11 Jun) 1977 (Cont)
Part S. ⊥ Waveform Display

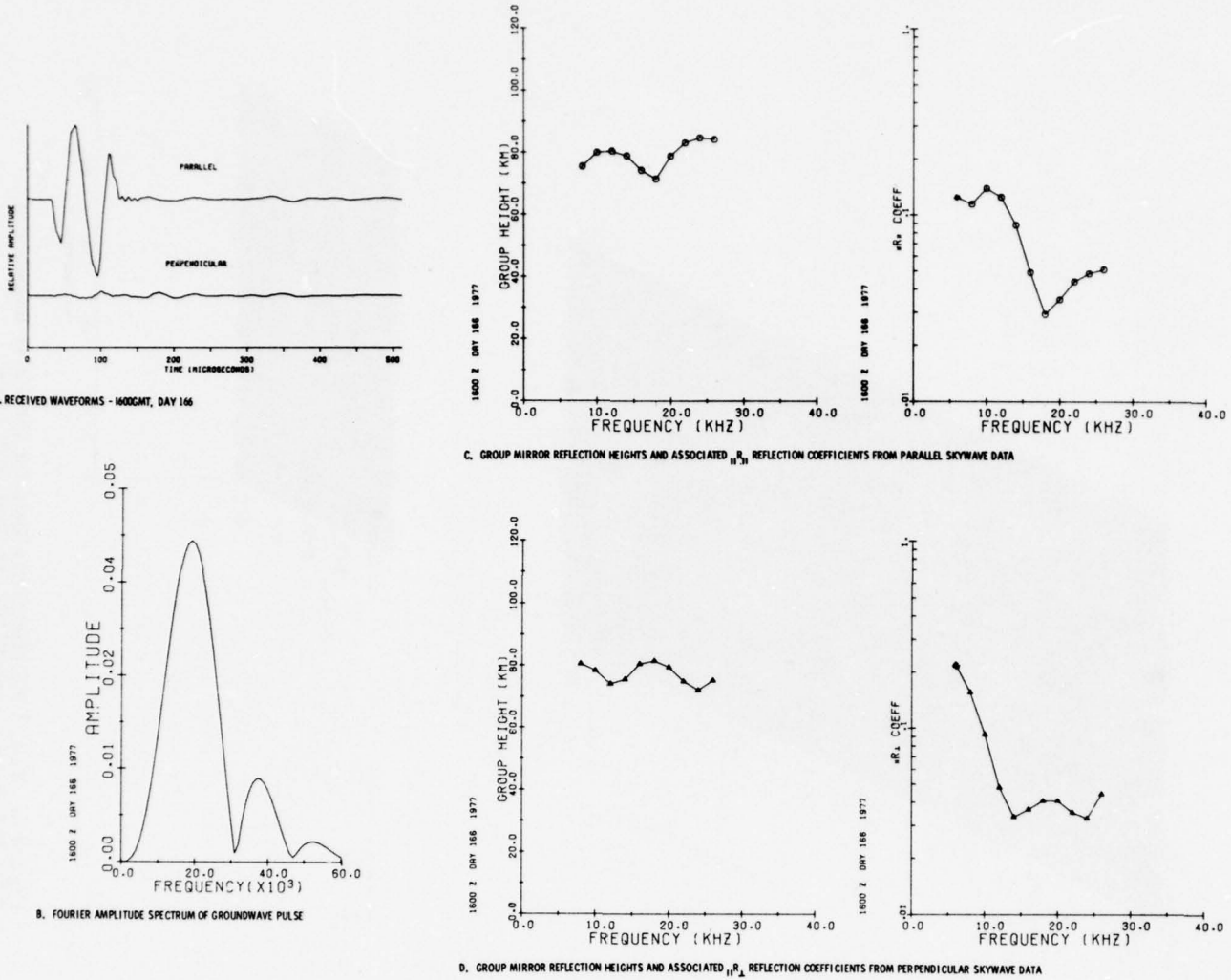


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 163 (12 Jun) — DAY 169 (18 Jun) 1977

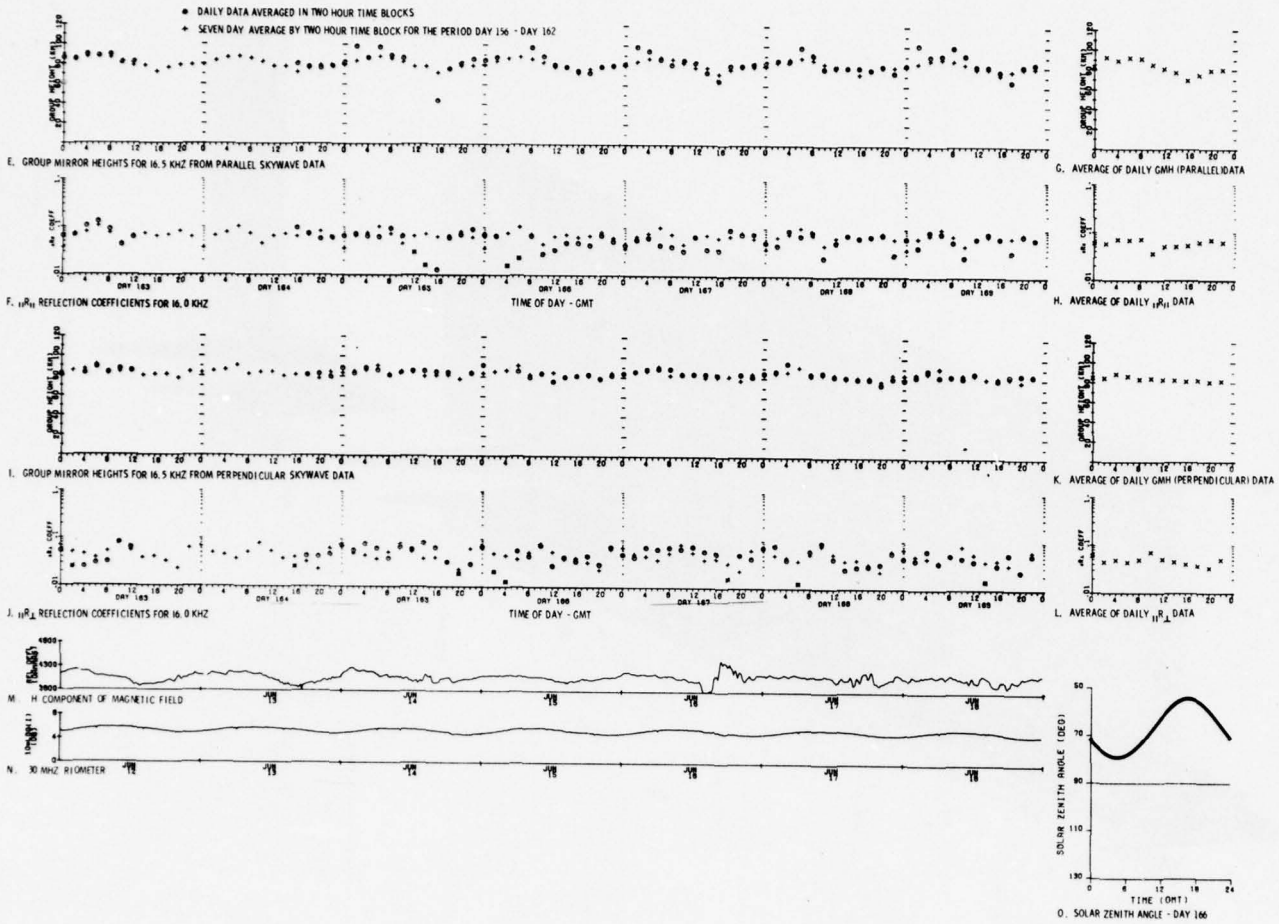


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 163 (12 Jun) – DAY 169 (18 Jun) 1977 (Cont)

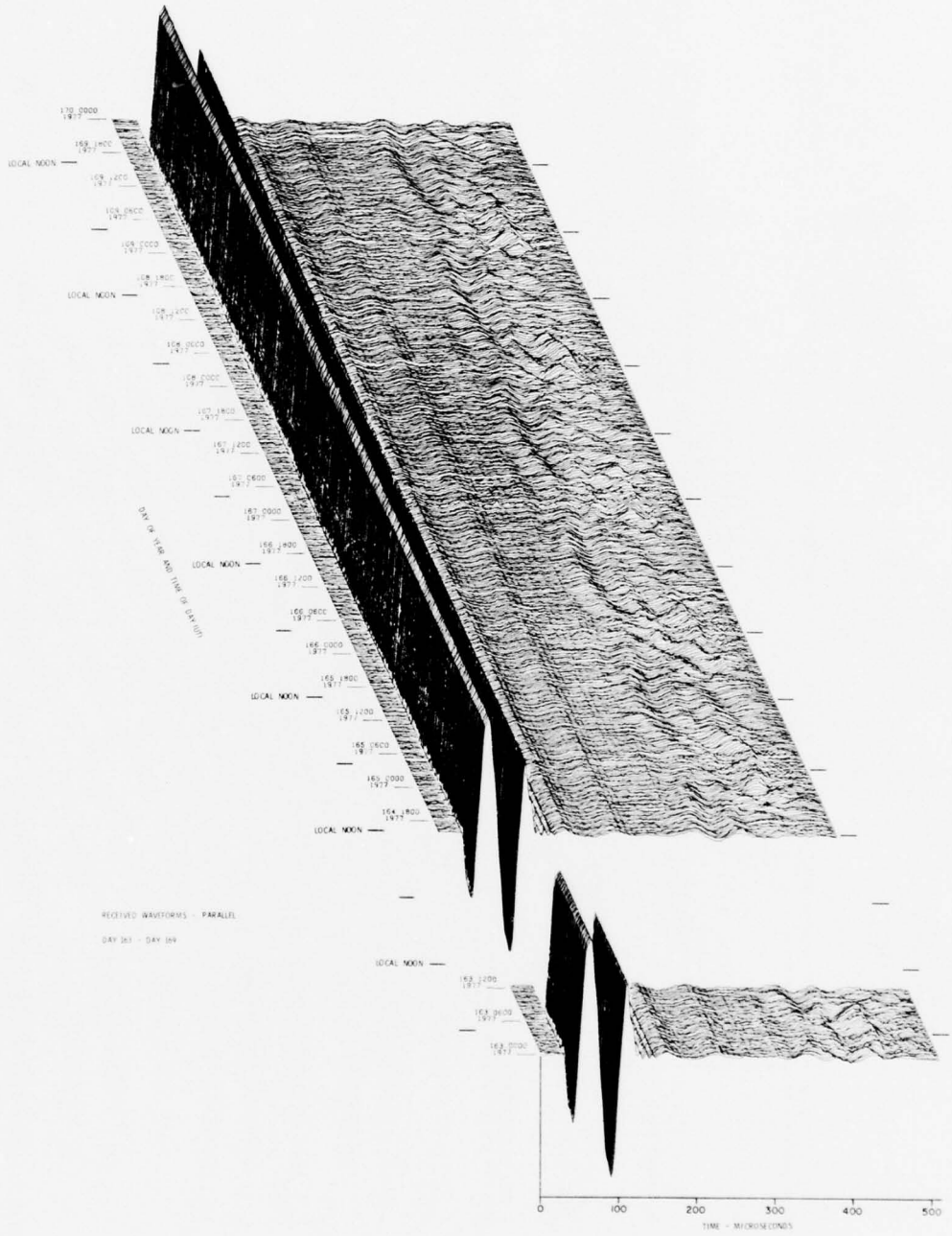


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 163 (12 Jun) — DAY 169 (18 Jun) 1977 (Cont)
Part R. II Waveform Display

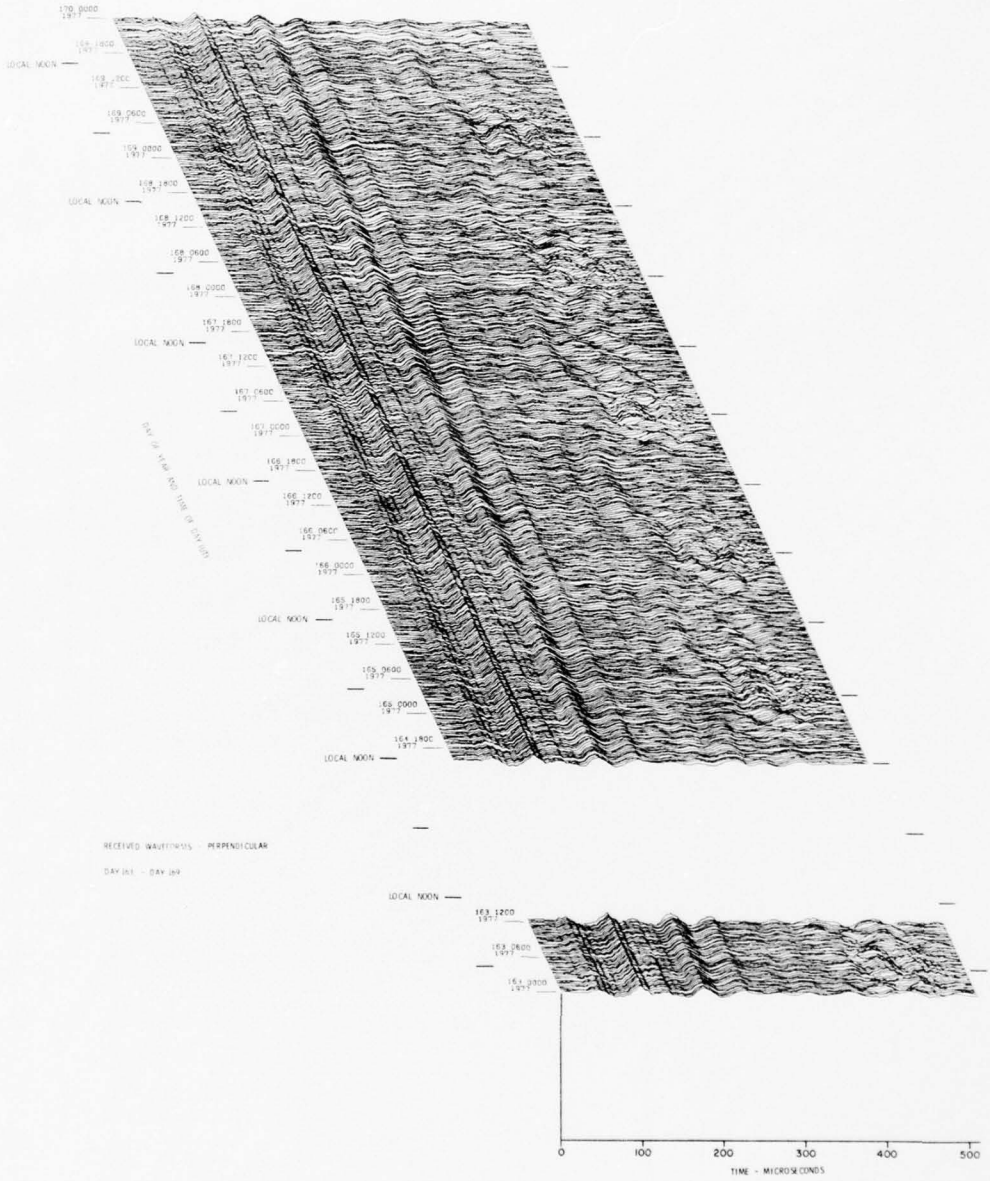
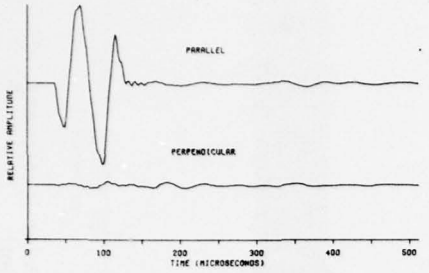
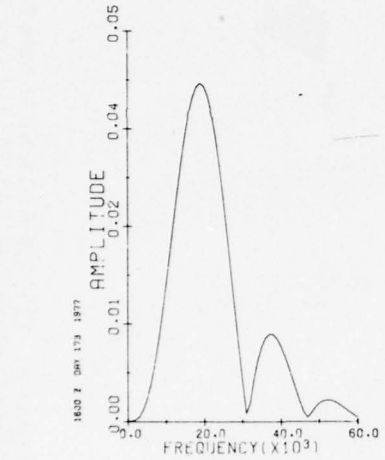


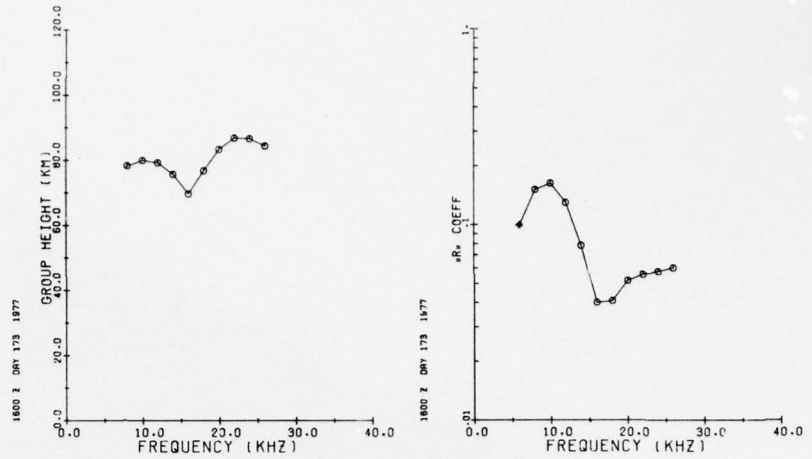
Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 163 (12 Jun) – DAY 169 (18 Jun) 1977 (Cont)
Part S. ⊥ Waveform Display



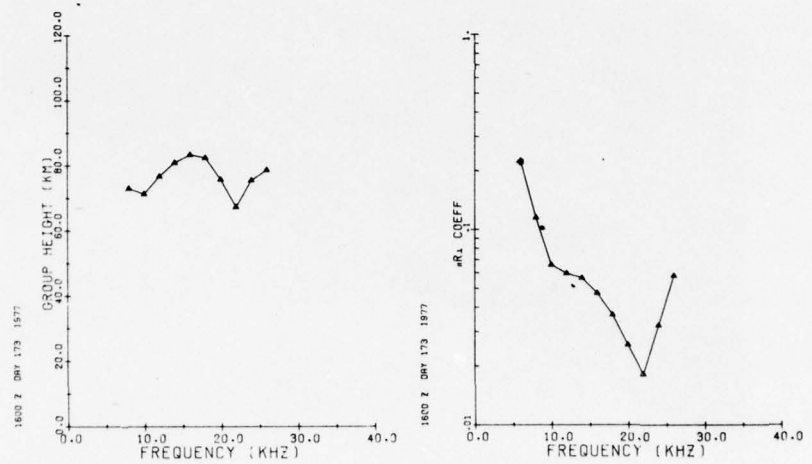
RECEIVED WAVEFORMS - 1600GMT, DAY 173



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE



C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $|R_{\parallel}|$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $|R_{\perp}|$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 170 (19 Jun) — DAY 176 (25 Jun) 1977

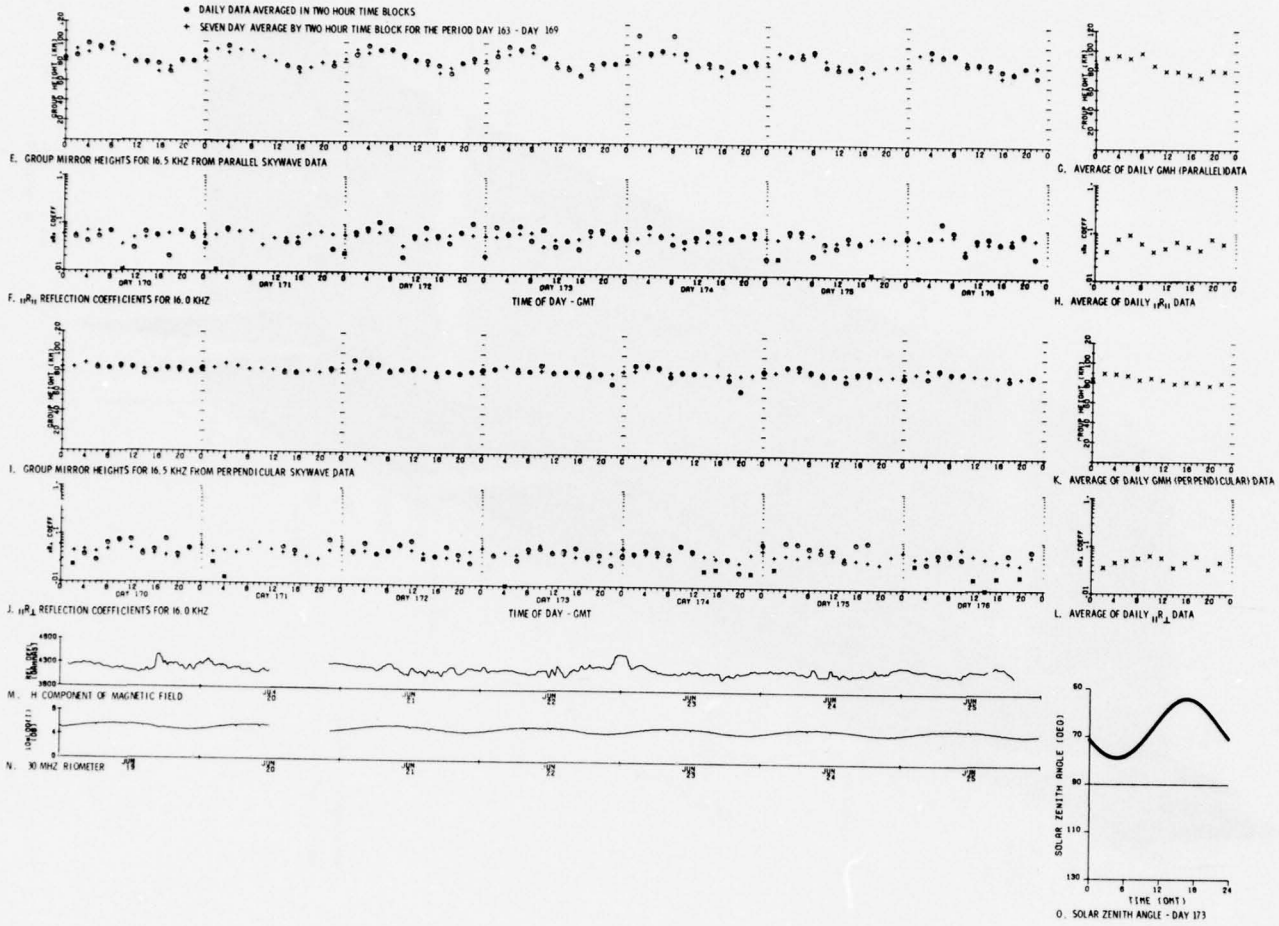


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 170 (19 Jun) — DAY 176 (25 Jun) 1977 (Cont)

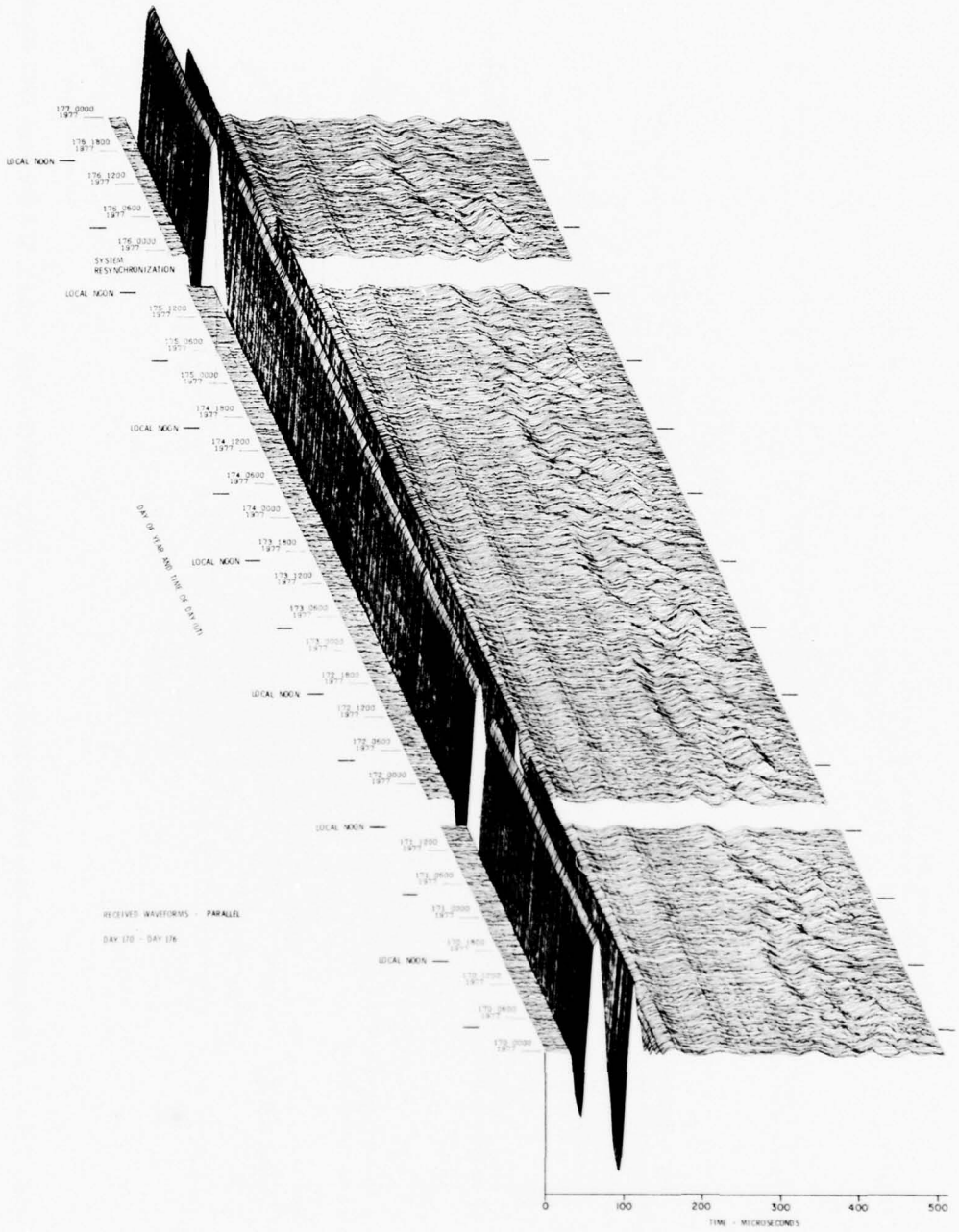


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 170 (19 Jun) – DAY 176 (25 Jun) 1977 (Cont)
Part R. II Waveform Display

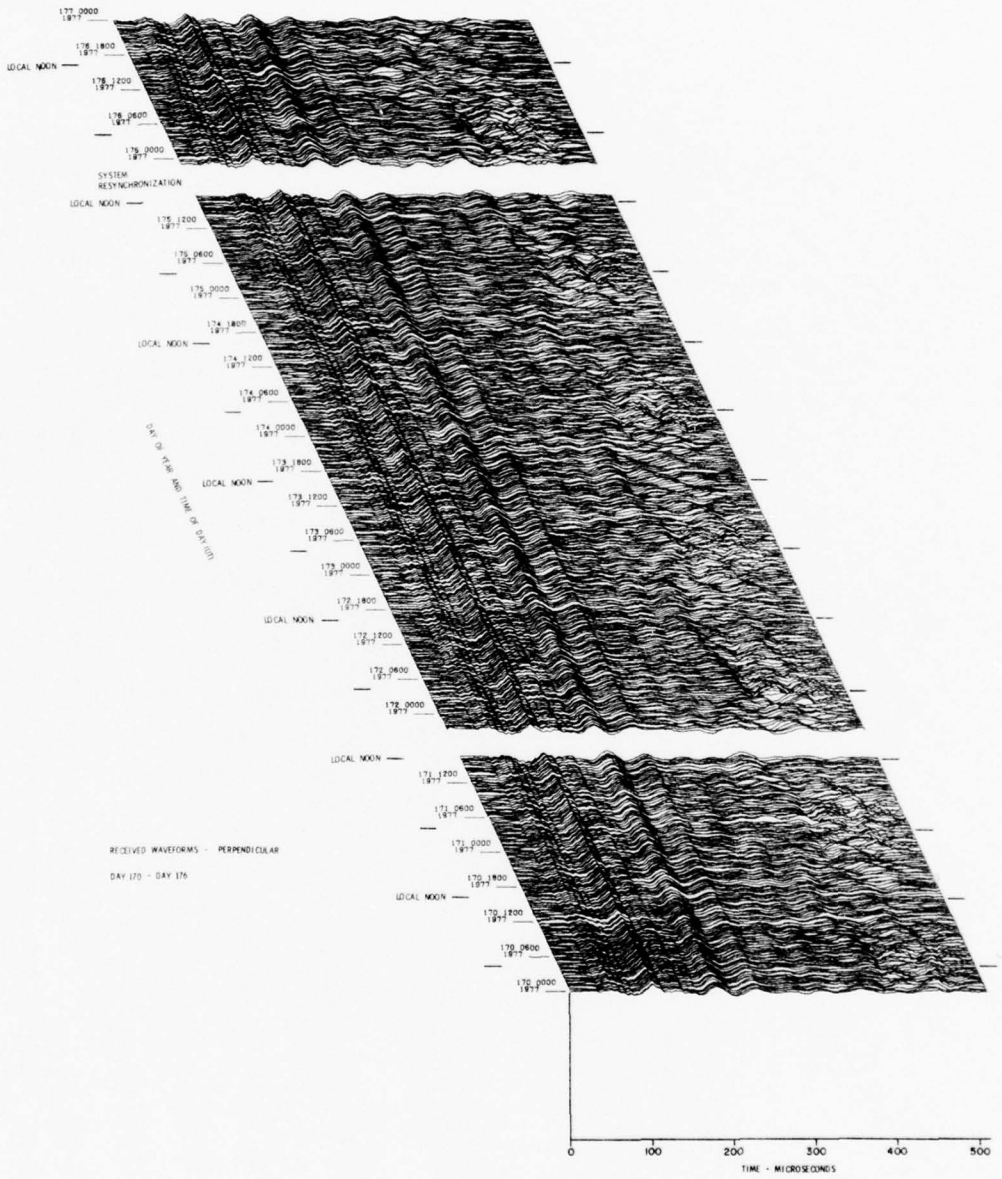


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 170 (19 Jun) – DAY 176 (25 Jun) 1977 (Cont)
Part S. ⊥ Waveform Display

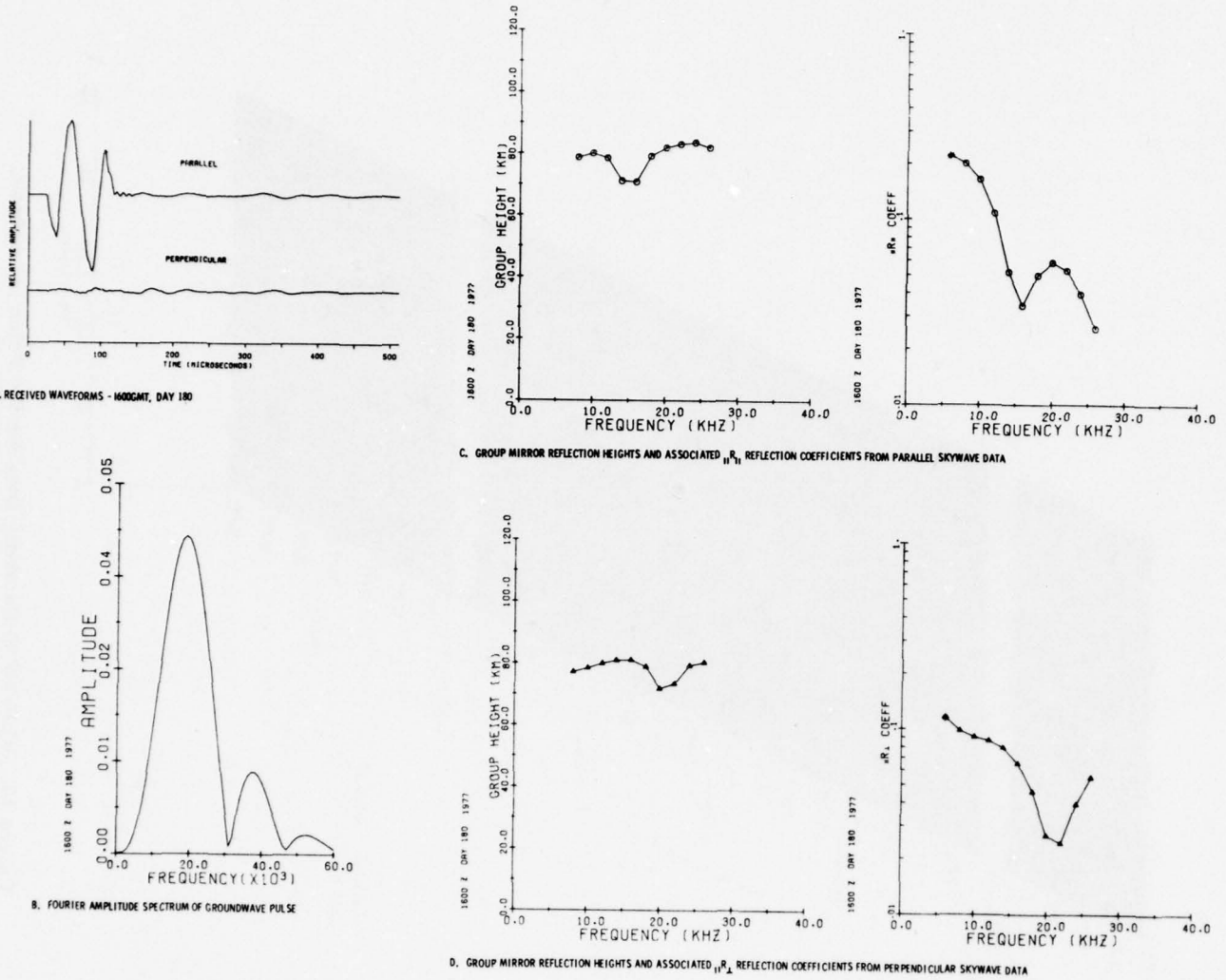


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 177 (26 Jun) — DAY 183 (2 Jul) 1977

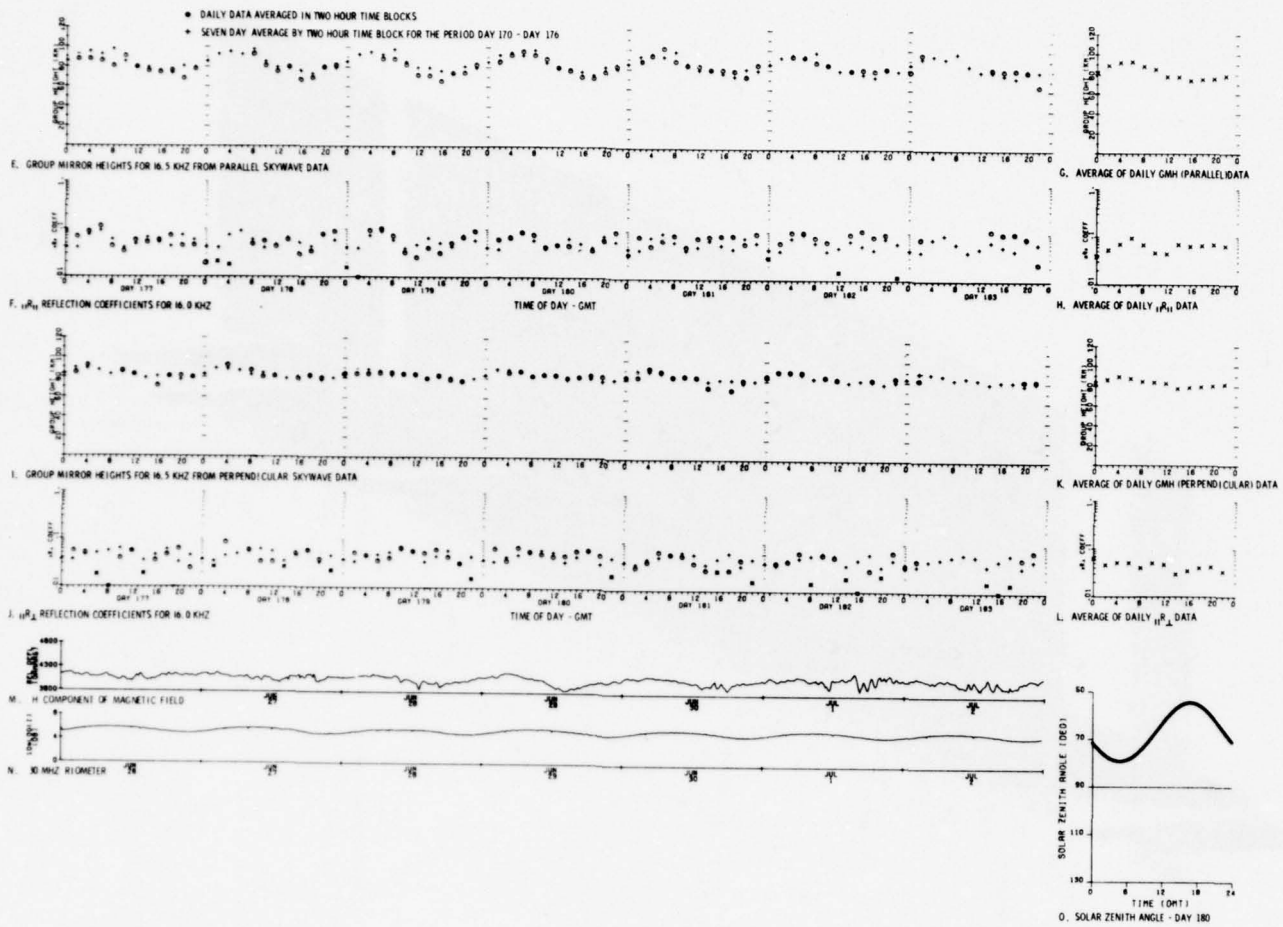


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 177 (26 Jun) — DAY 183 (2 Jul) 1977 (Cont)

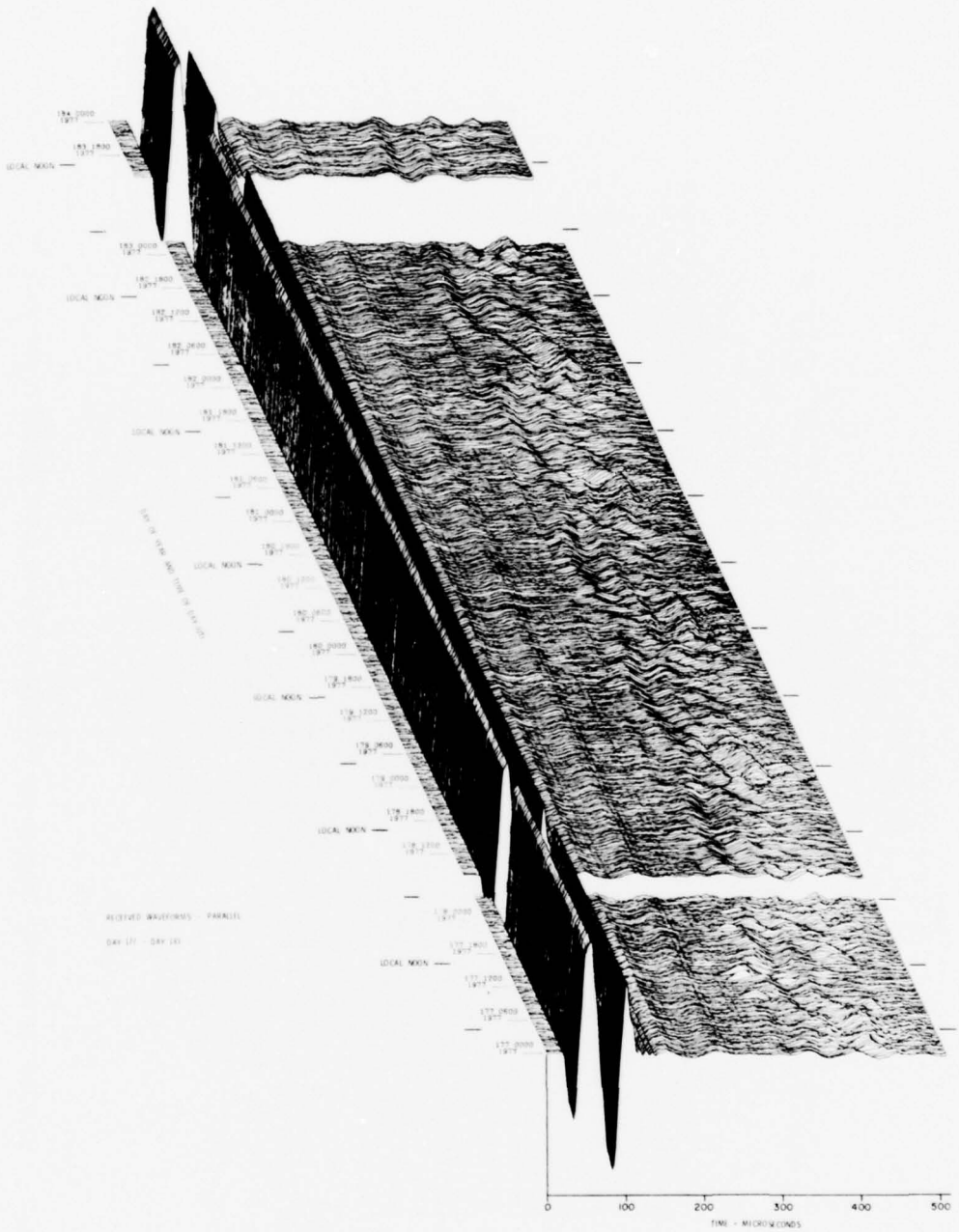


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 177 (26 Jun) – DAY 183 (2 Jul) 1977 (Cont)
Part R. II Waveform Display

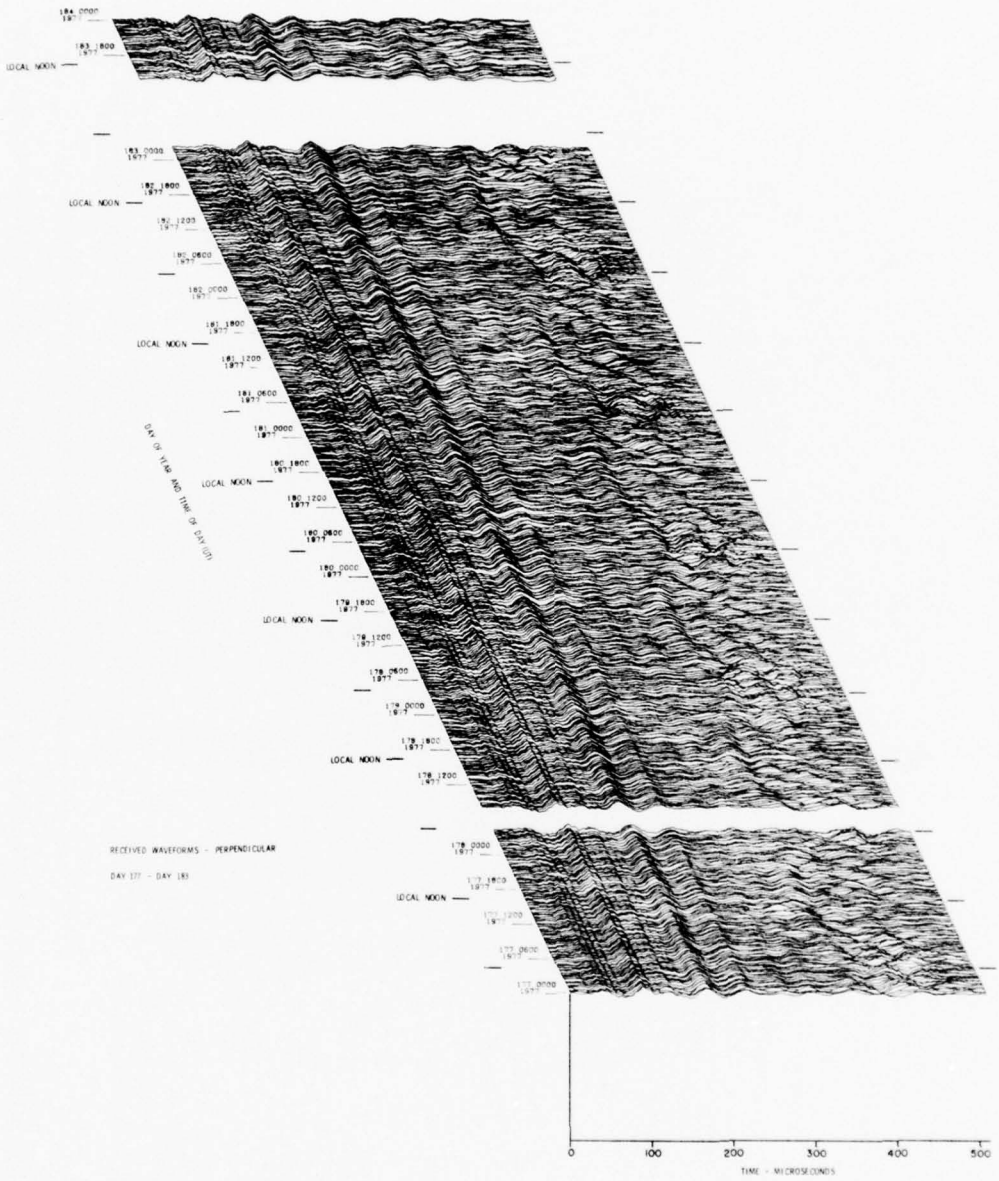


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 177 (26 Jun) — DAY 183 (2 Jul) 1977 (Cont)
Part S. ⊥ Waveform Display

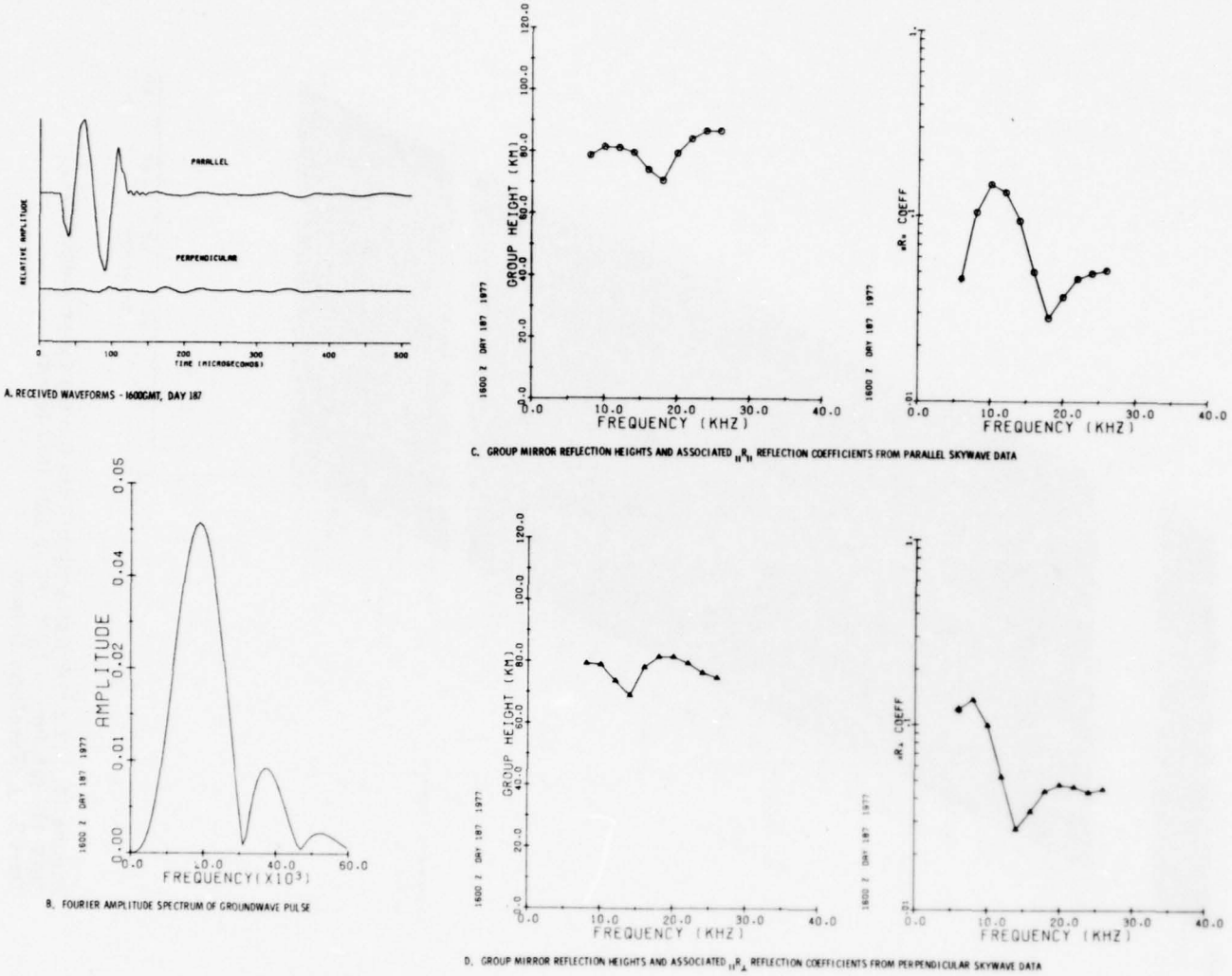


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 184 (3 Jul) – DAY 190 (9 Jul) 1977

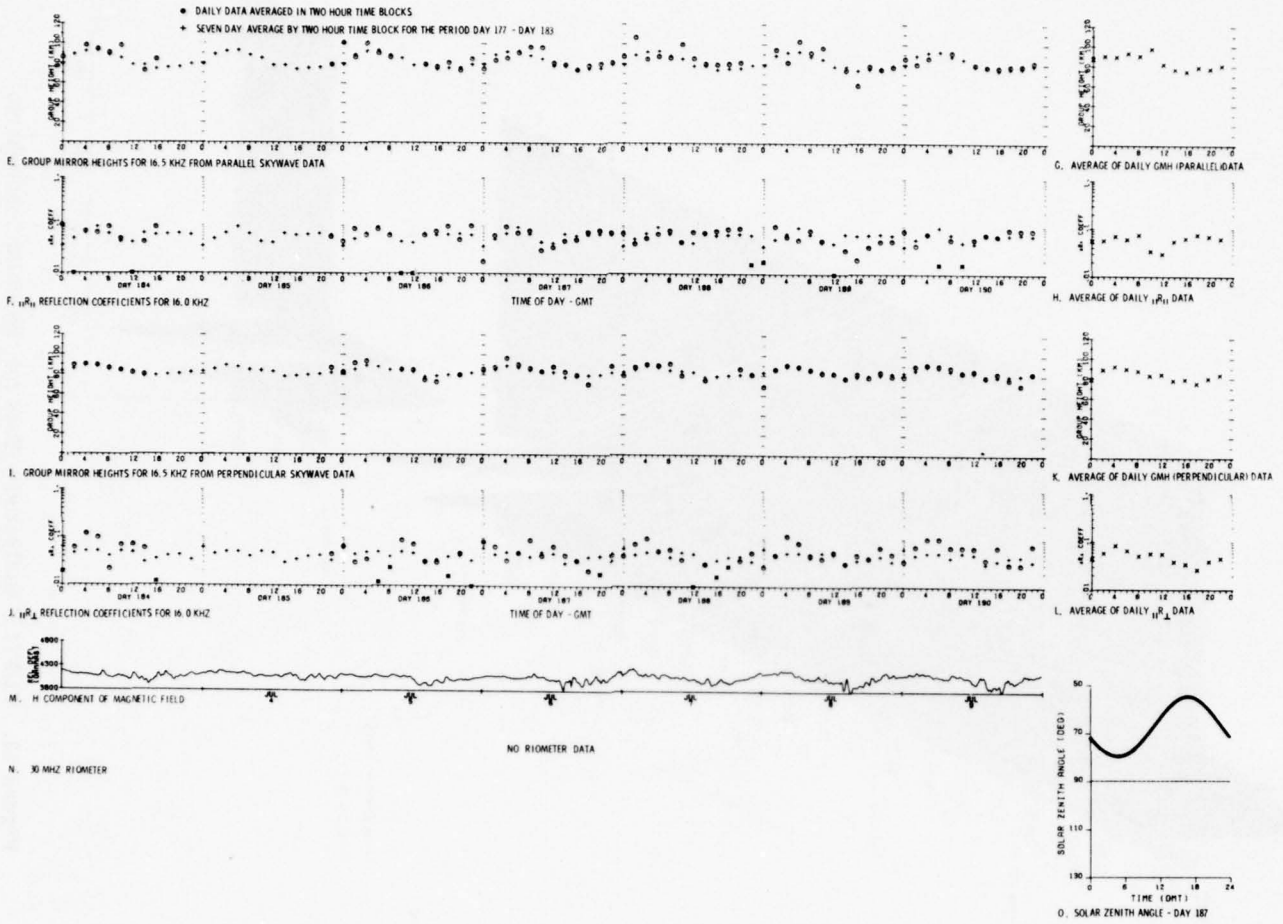


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 184 (3 Jul) — DAY 190 (9 Jul) 1977 (Cont)

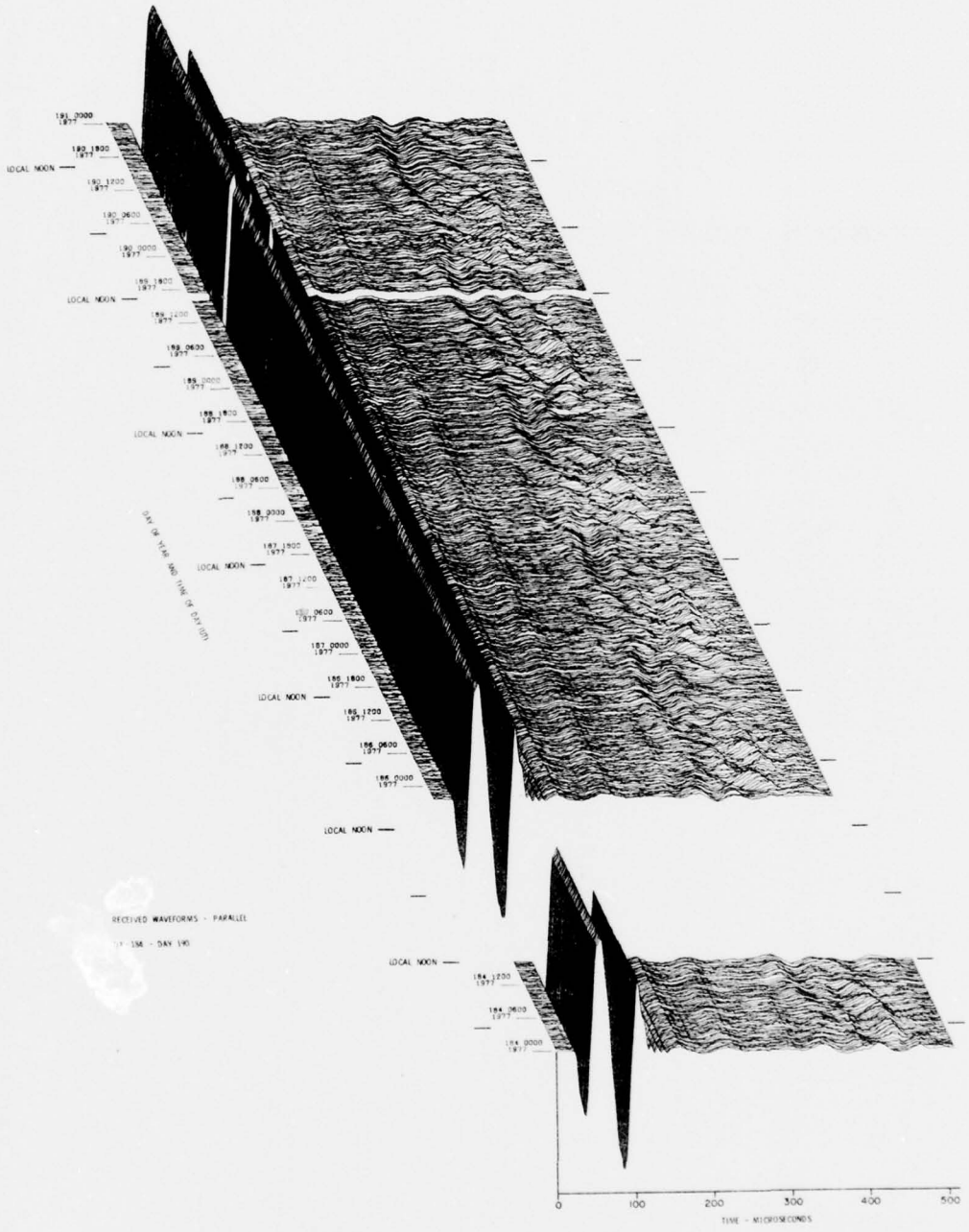


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 184 (3 Jul) – DAY 190 (9 Jul) 1977 (Cont)
Part R. II Waveform Display

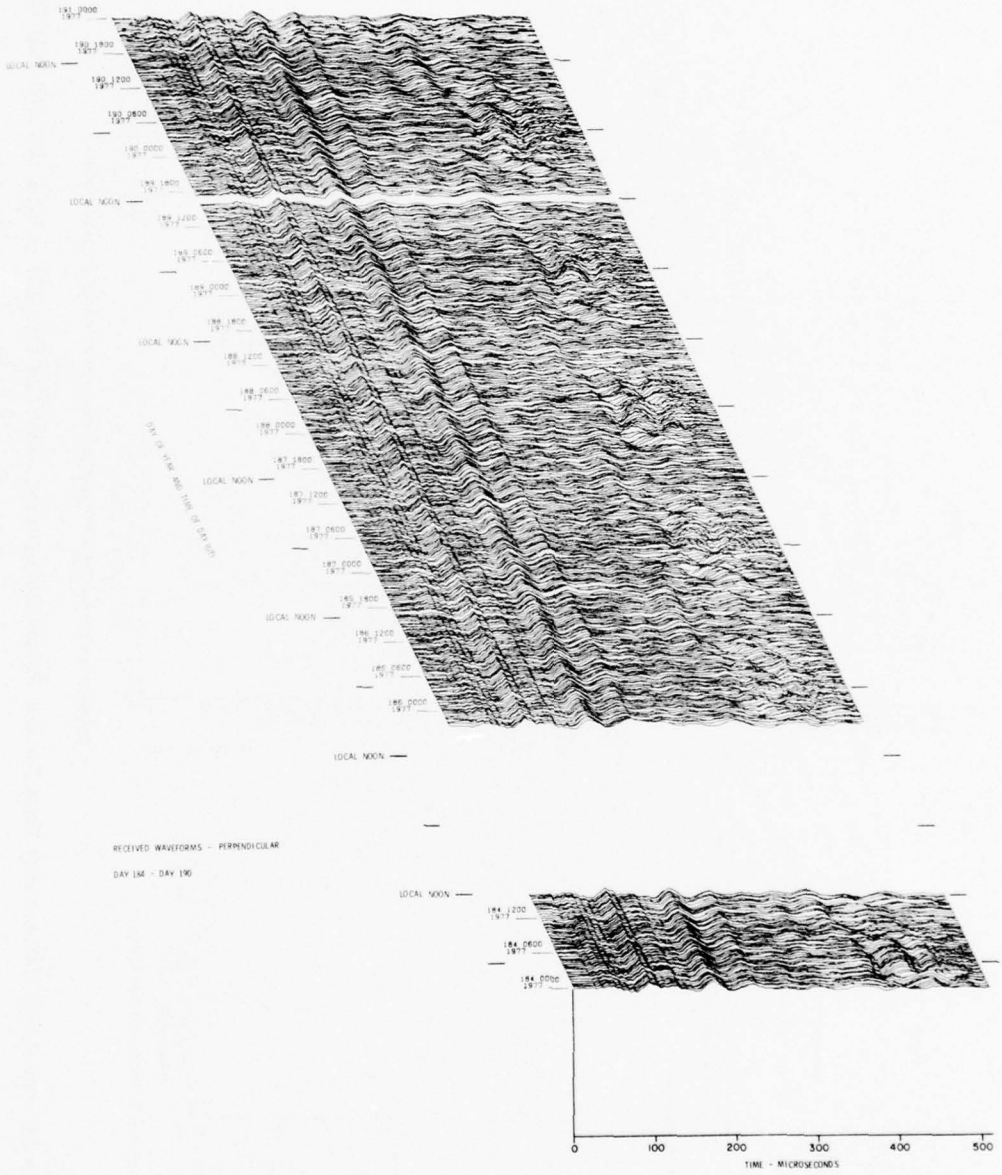


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 184 (3 Jul) — DAY 190 (9 Jul) 1977 (Cont)
Part S. ⊥ Waveform Display

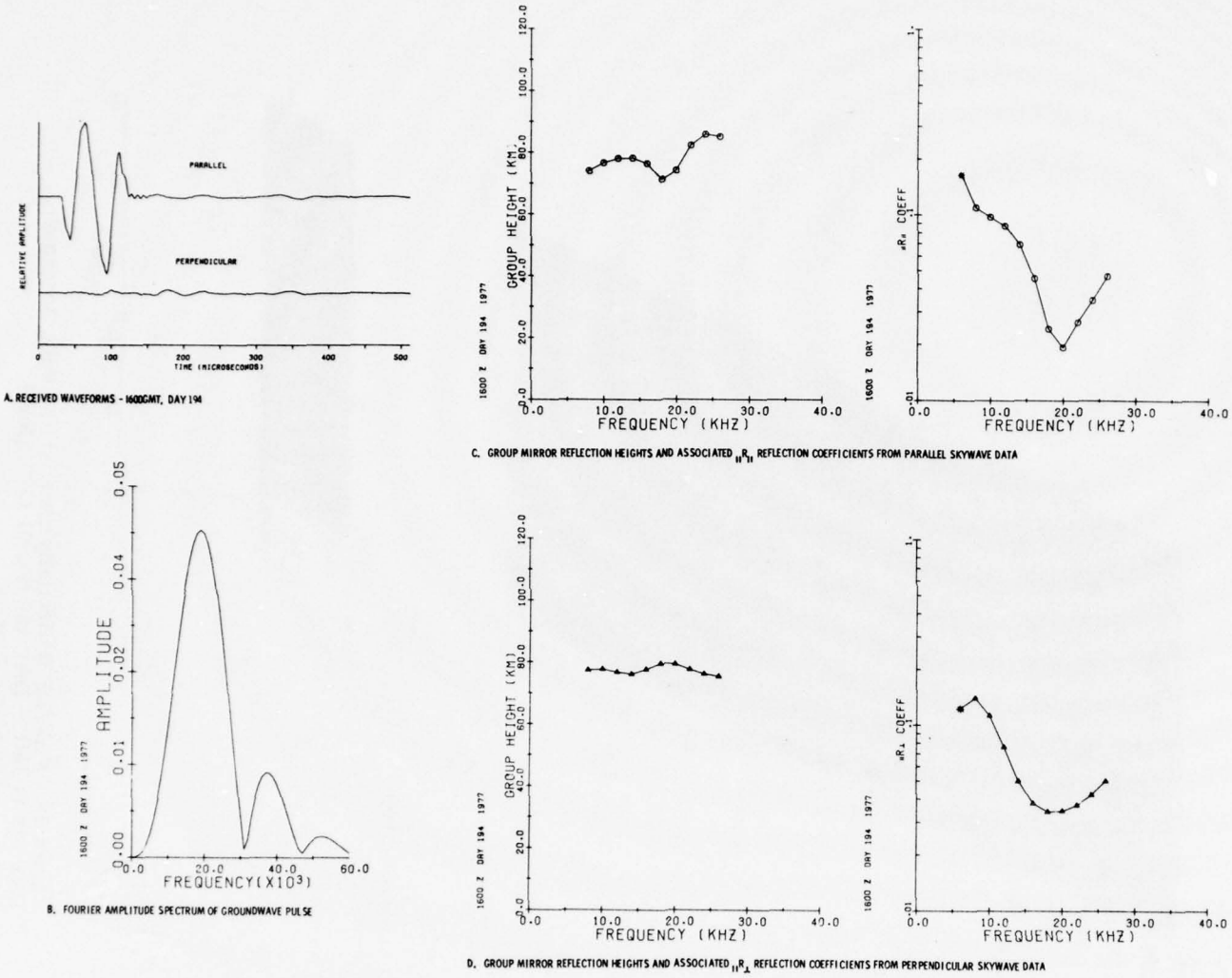


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 191 (10 Jul) — DAY 197 (16 Jul) 1977

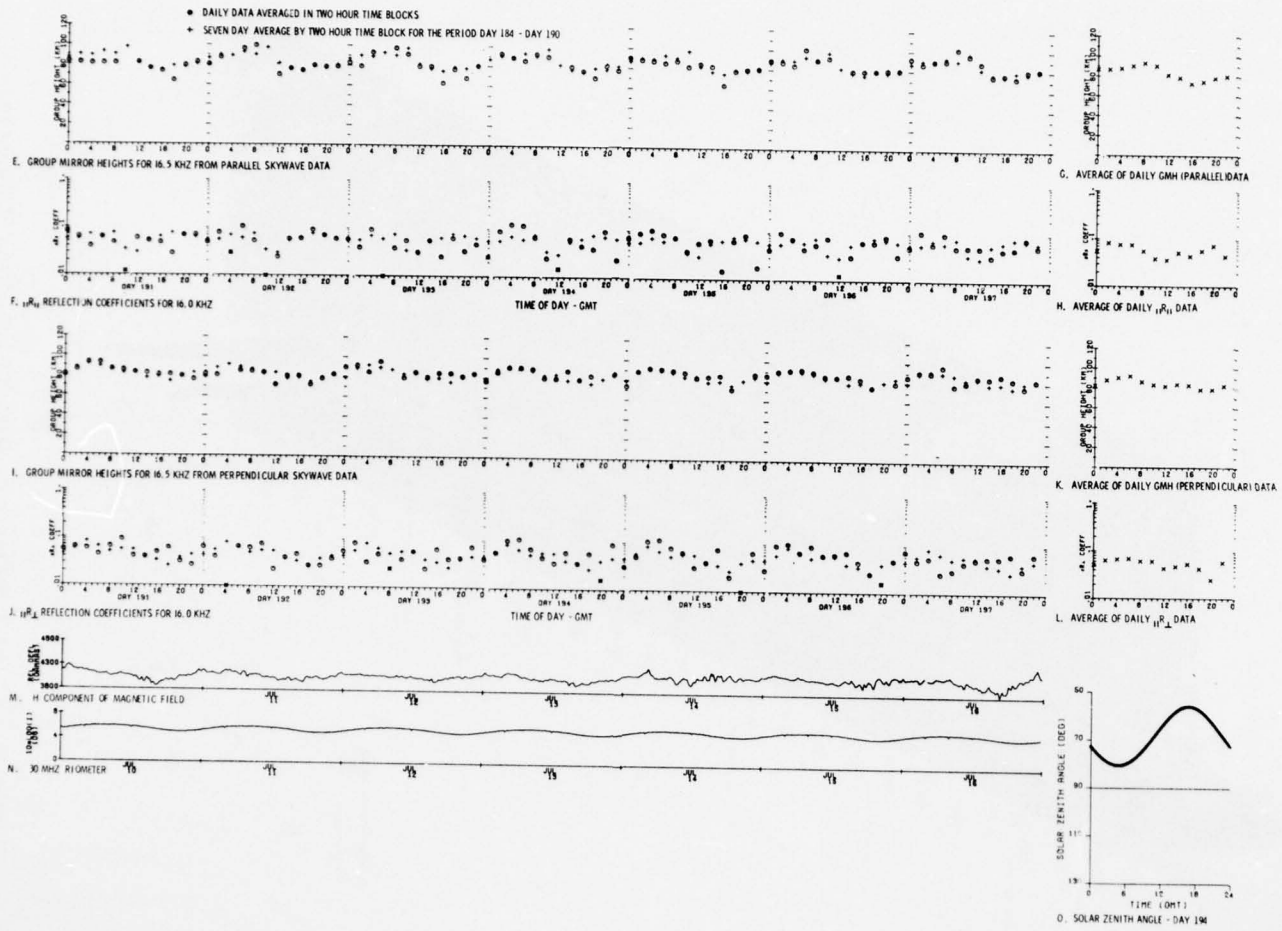


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 191 (10 Jul) — DAY 197 (16 Jul) 1977 (Cont)

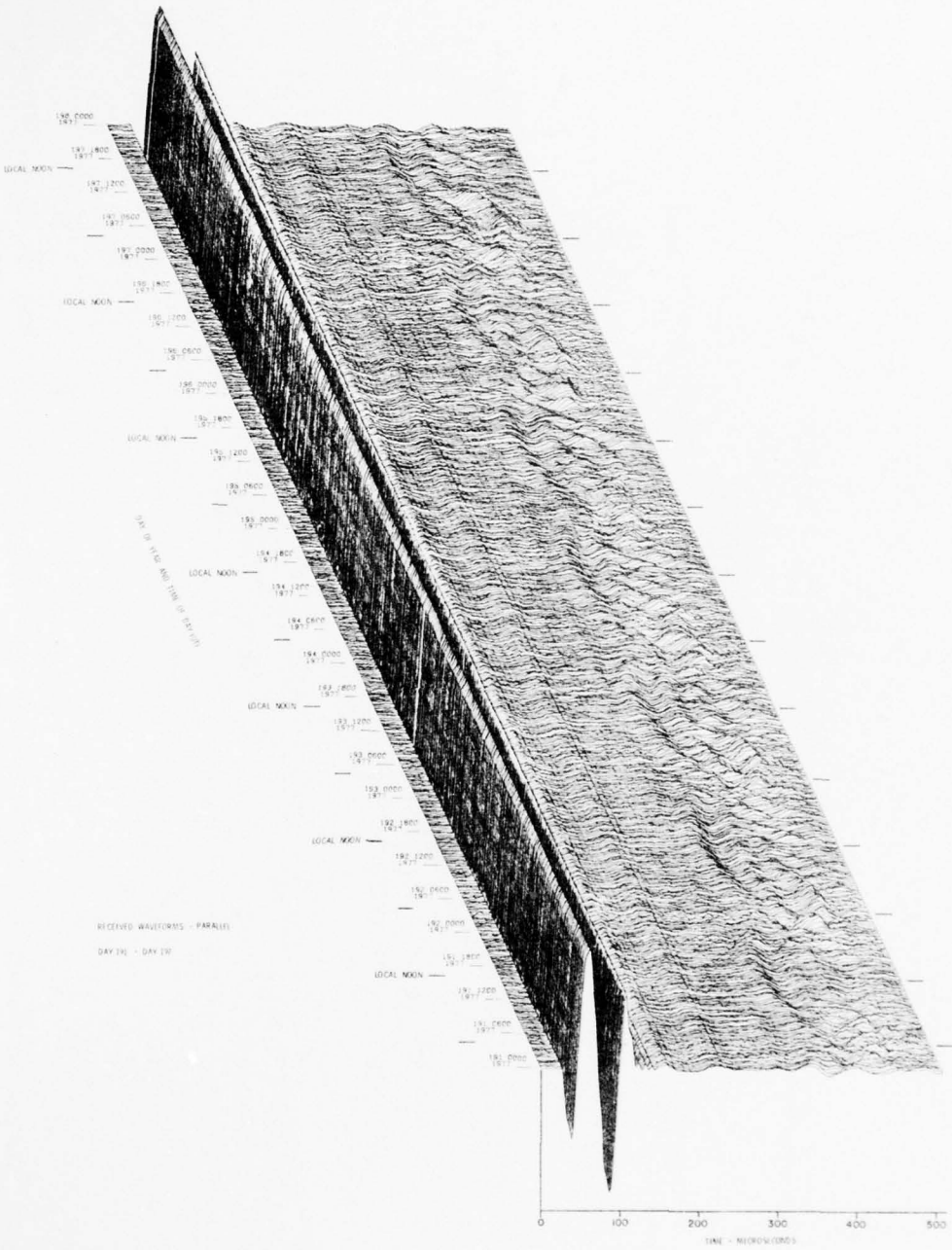


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 191 (10 Jul) – DAY 197 (16 Jul) 1977 (Cont)
Part R. II Waveform Display

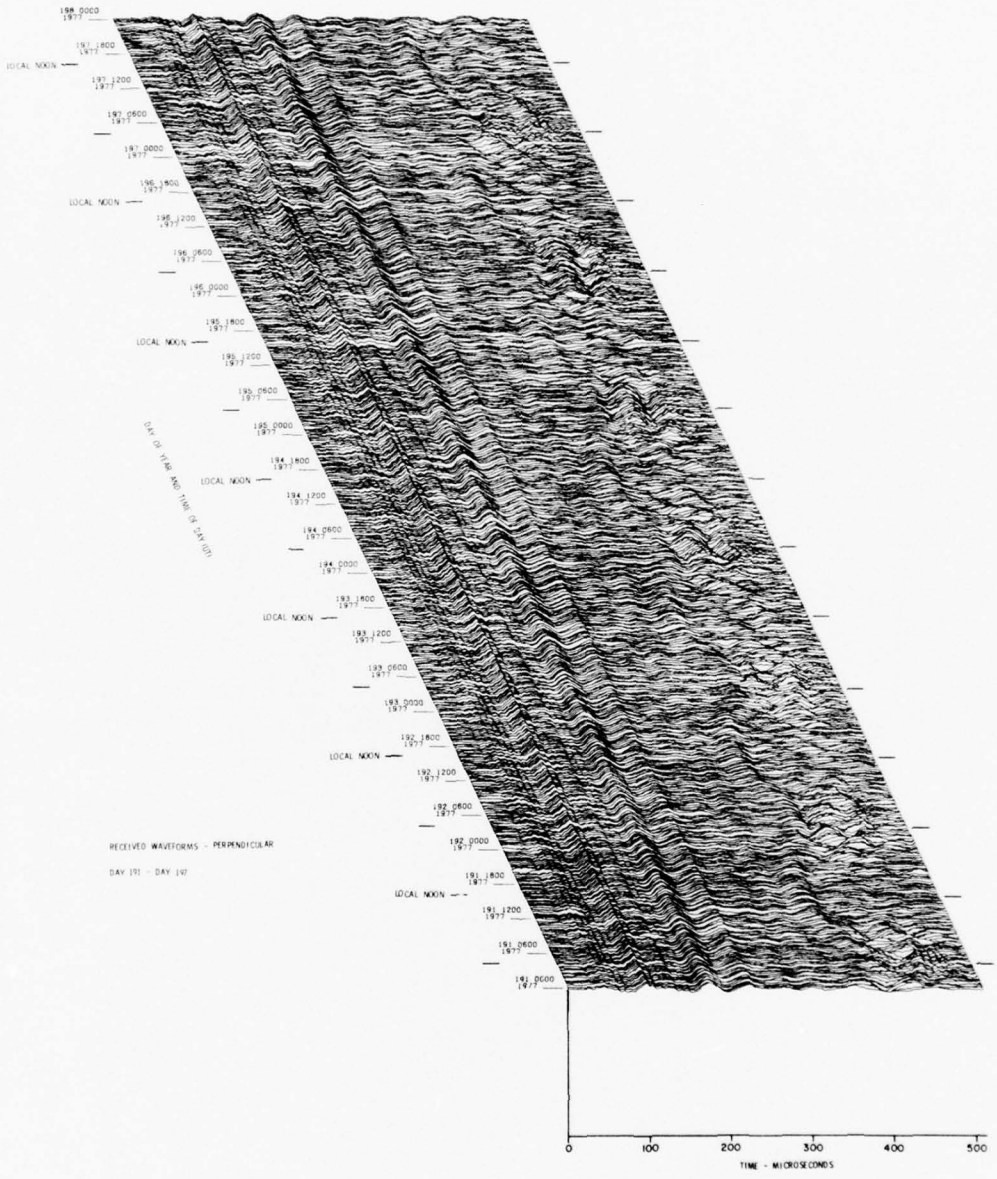


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 191 (10 Jul) – DAY 197 (16 Jul) 1977 (Cont)
Part S. ⊥ Waveform Display

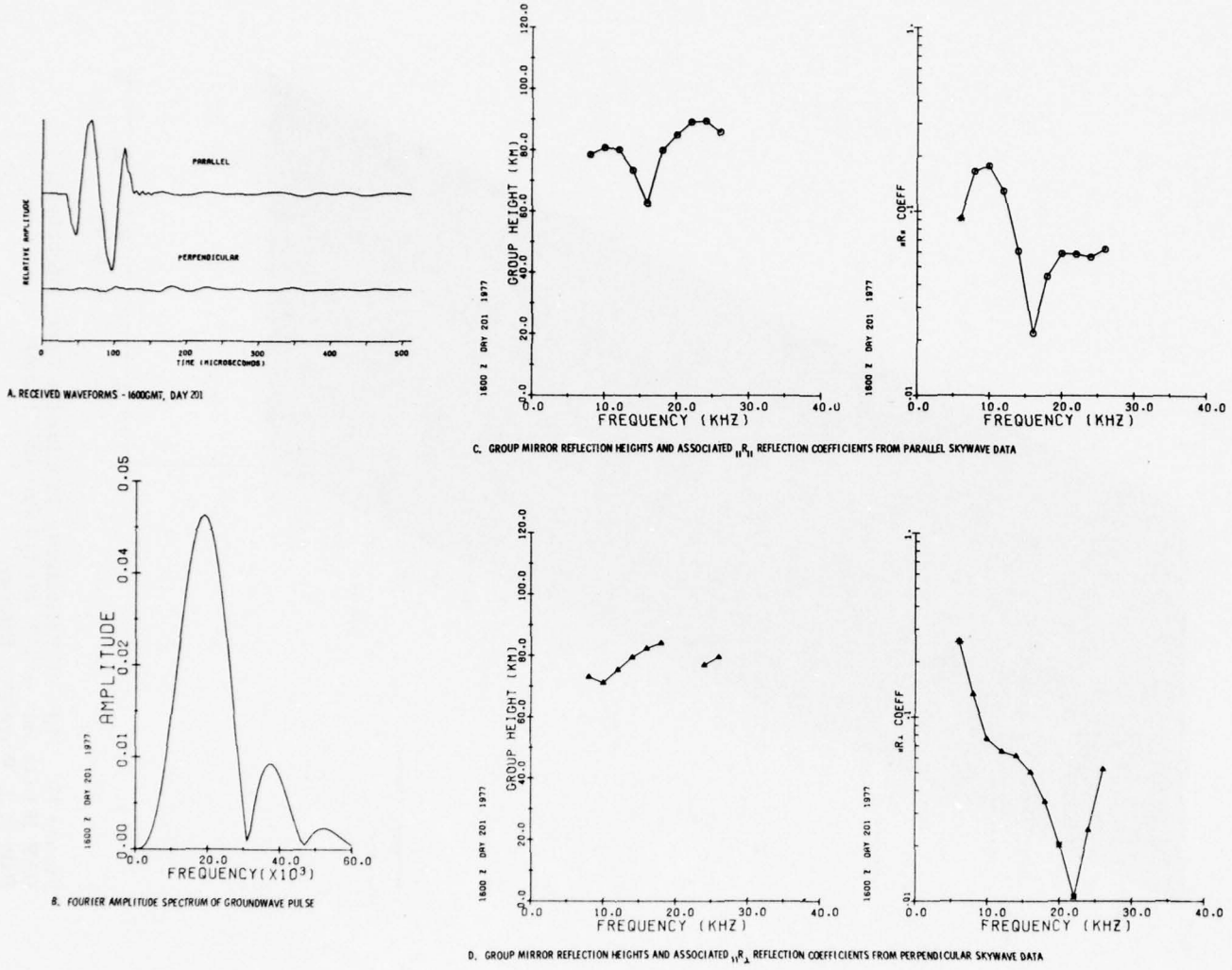


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 198 (17 Jul) — DAY 204 (23 Jul) 1977

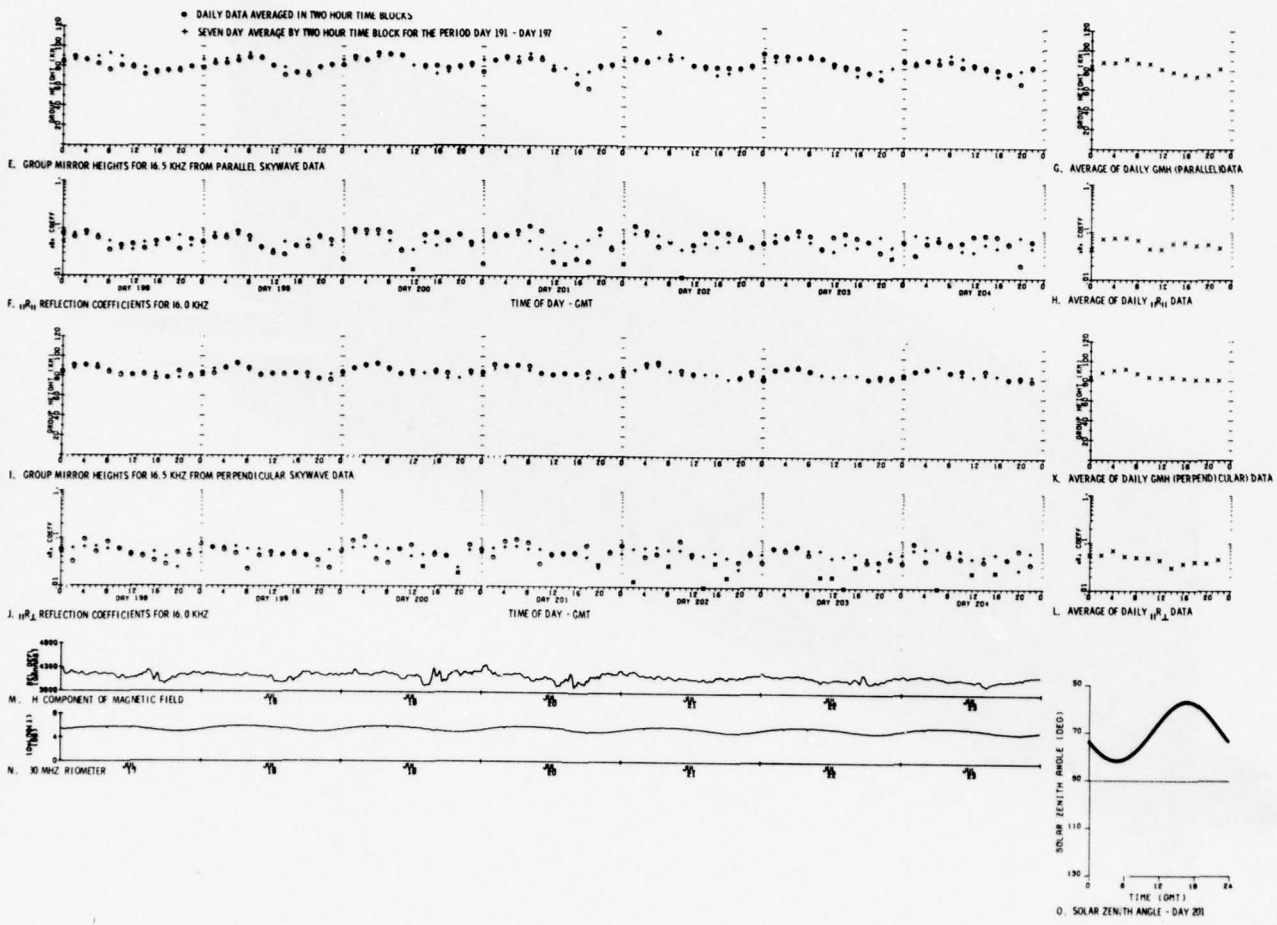


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 198 (17 Jul) – DAY 204 (23 Jul) 1977 (Cont)

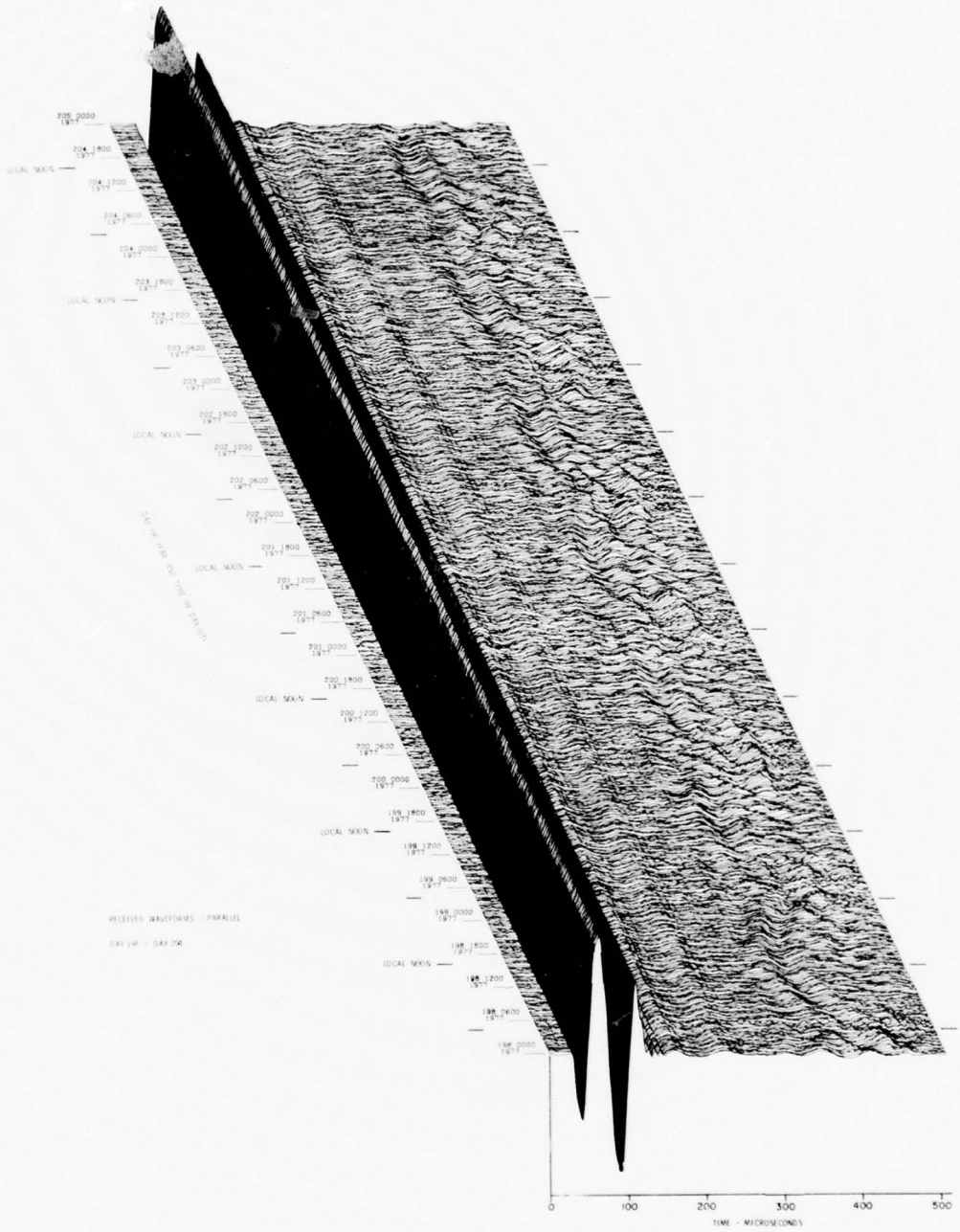


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 198 (17 Jul) — DAY 204 (23 Jul) 1977 (Cont)
Part R. II Waveform Display

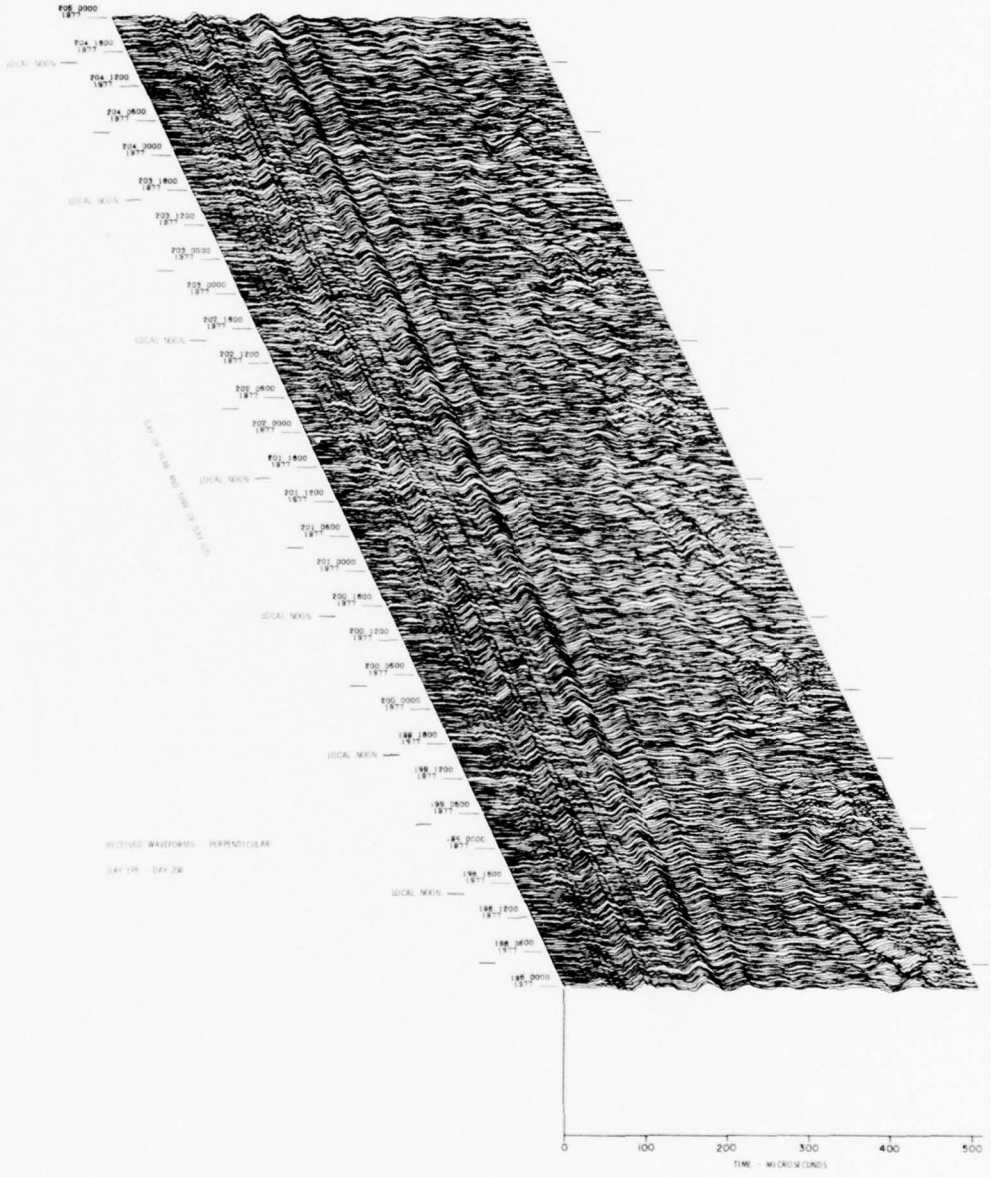


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 198 (17 Jul) – DAY 204 (23 Jul) 1977 (Cont)
Part S. ⊥ Waveform Display

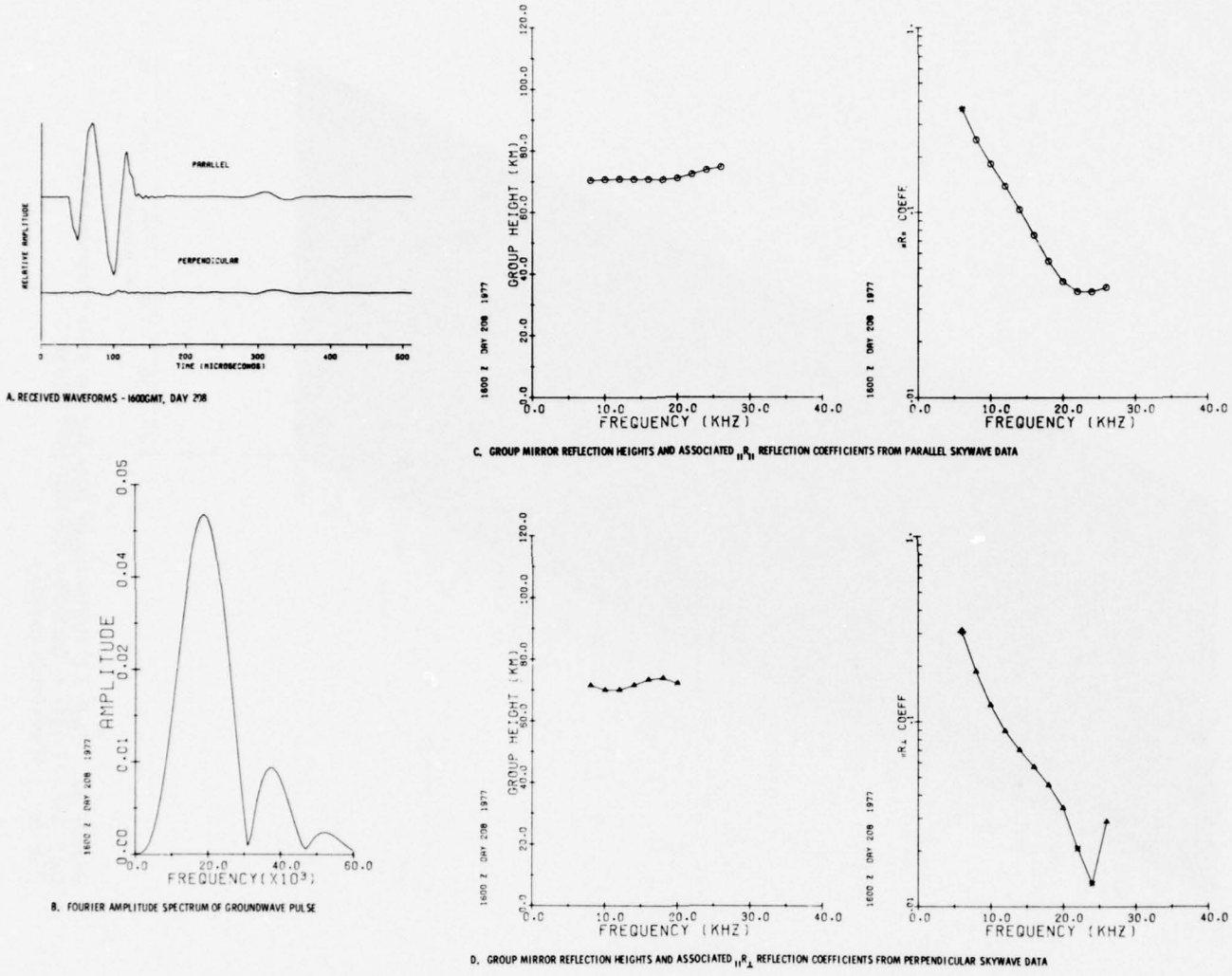


Figure 15. VLF/LF Reflectivity Data for Polar Ionosphere, DAY 205 (24 Jul) — DAY 211 (30 Jul) 1977

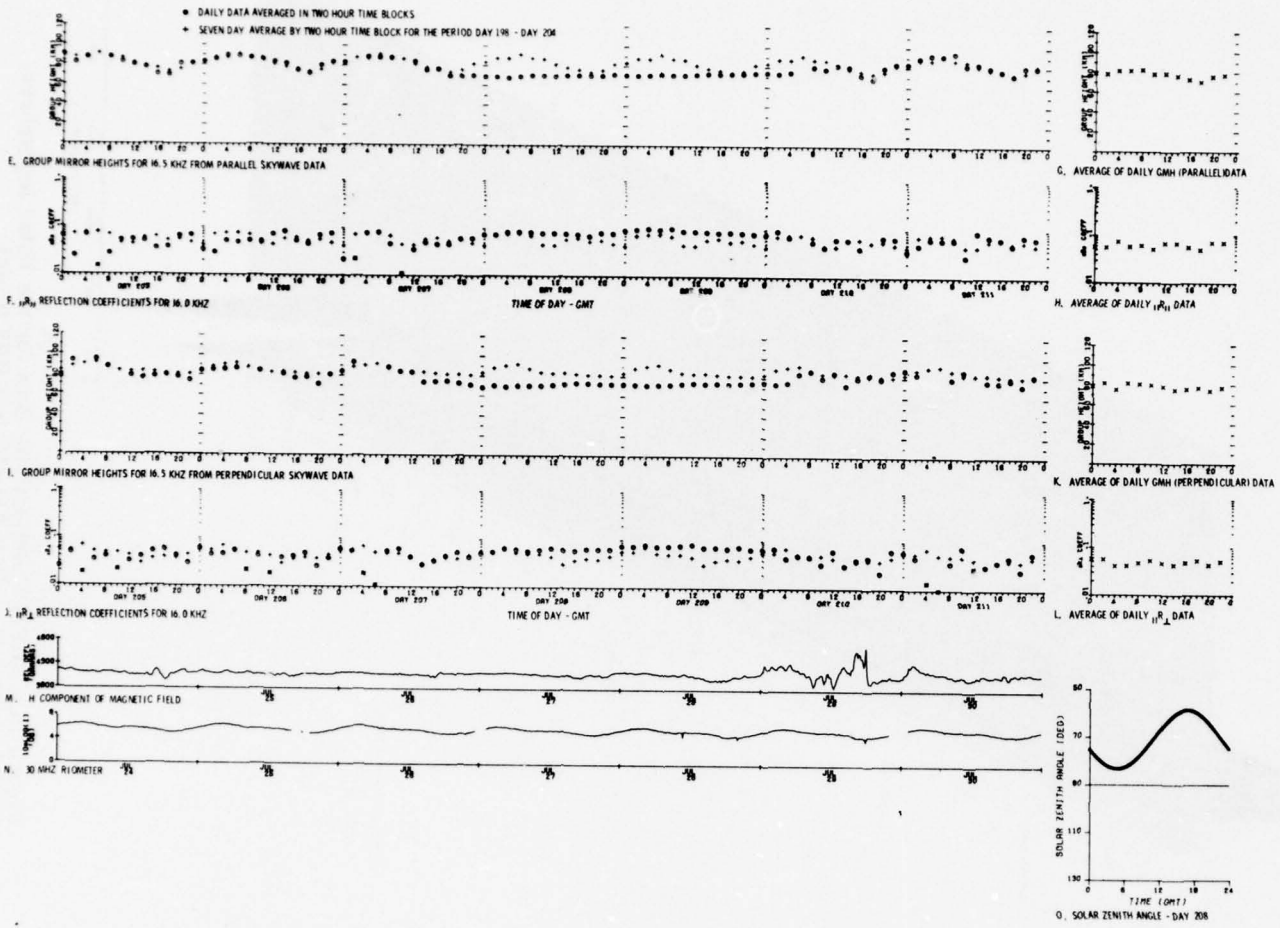


Figure 15. VLF/LF Reflectivity Data for Polar Ionosphere, DAY 205 (24 Jul) — DAY 211 (30 Jul) 1977 (Cont)

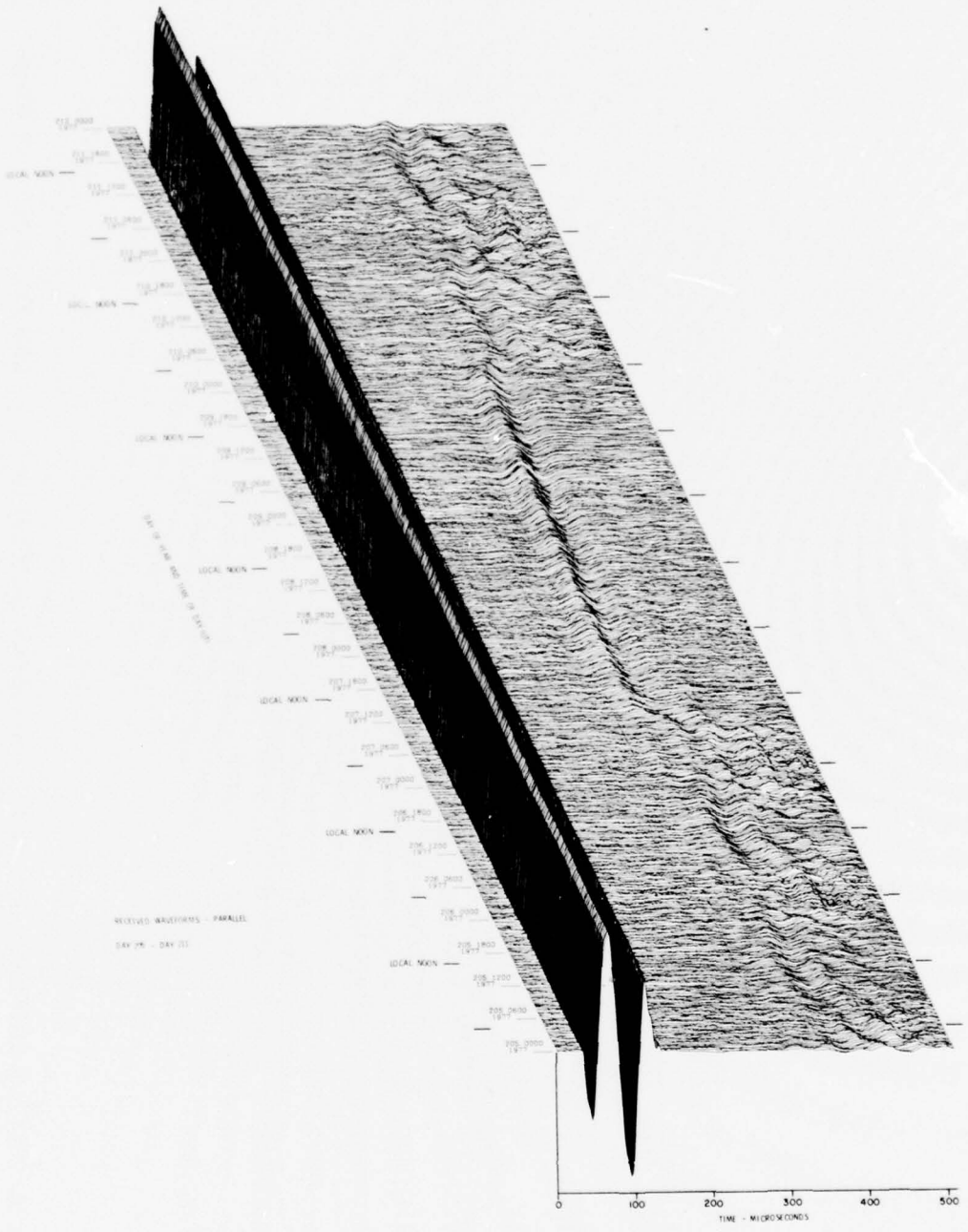


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 205 (24 Jul) – DAY 211 (30 Jul) 1977 (Cont)
Part R. II Waveform Display

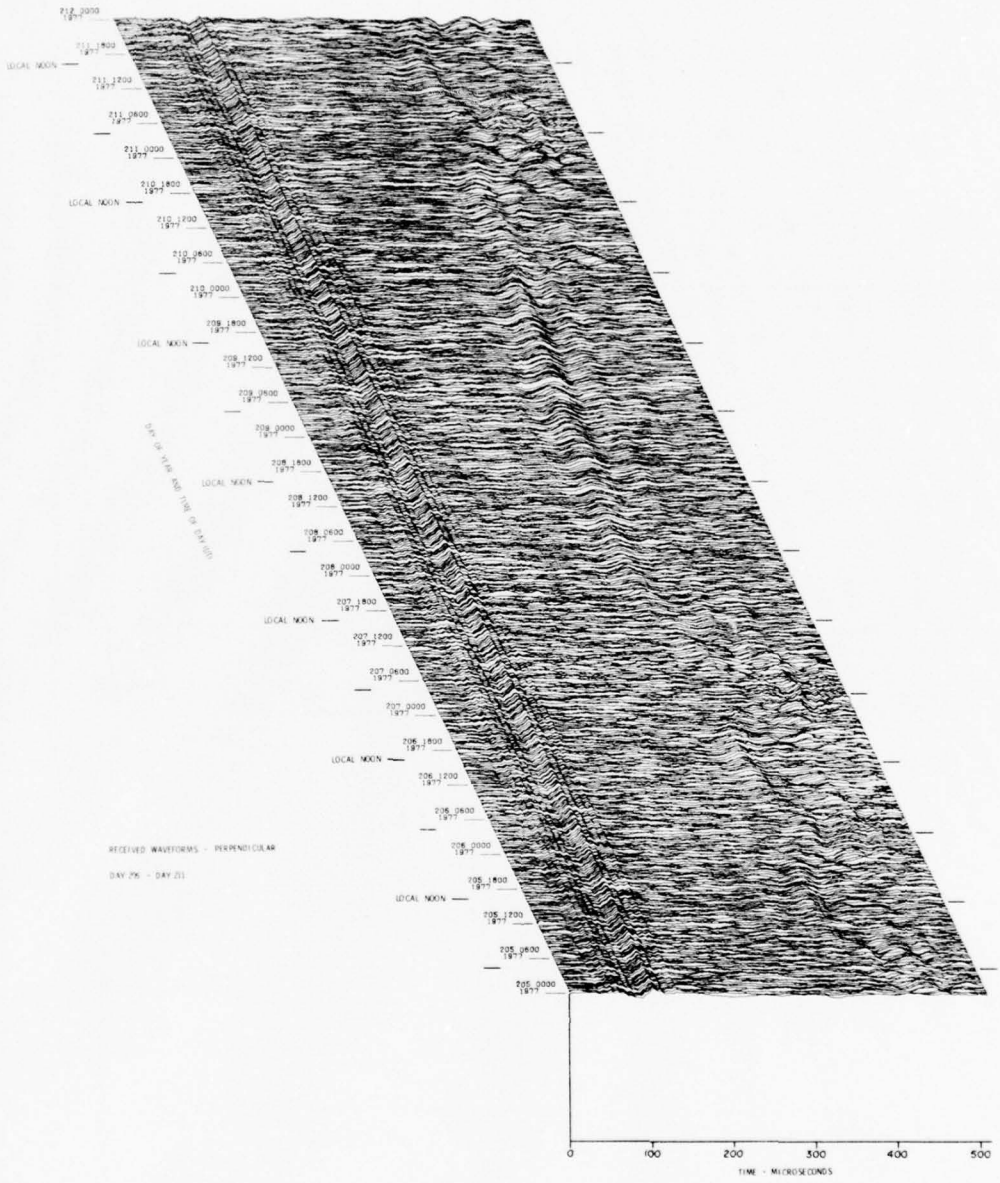
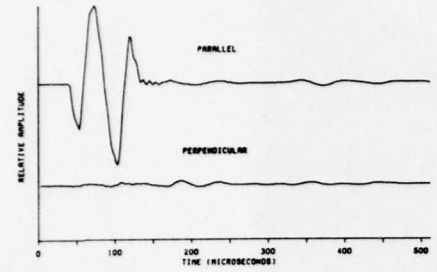
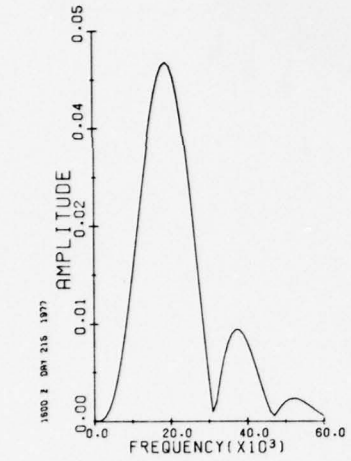


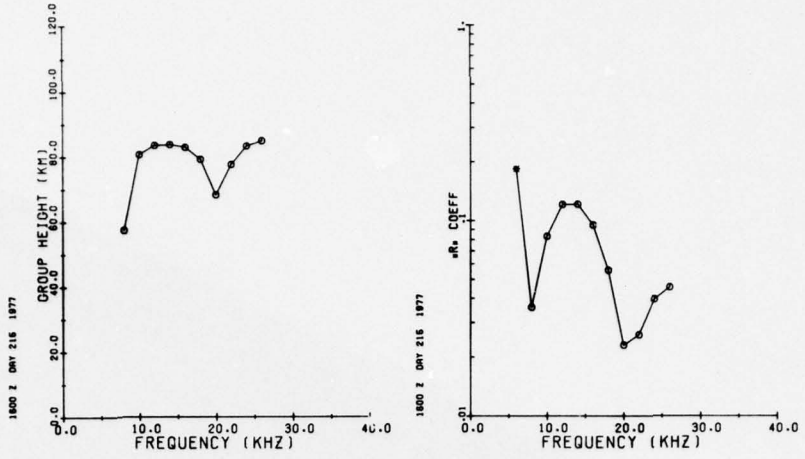
Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 205 (24 Jul) – DAY 211 (30 Jul) 1977 (Cont)
Part S. ⊥ Waveform Display



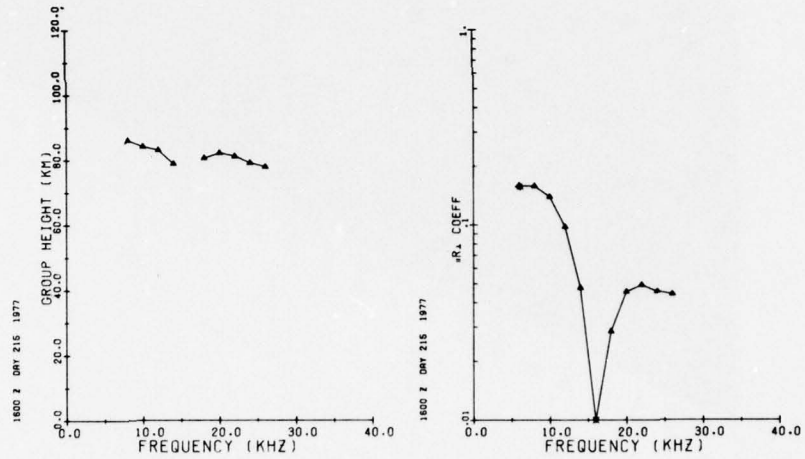
A. RECEIVED WAVEFORMS - 1600GMT, DAY 215



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE



C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\parallel}$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\perp}$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 212 (31 Jul) — DAY 218 (6 Aug) 1977

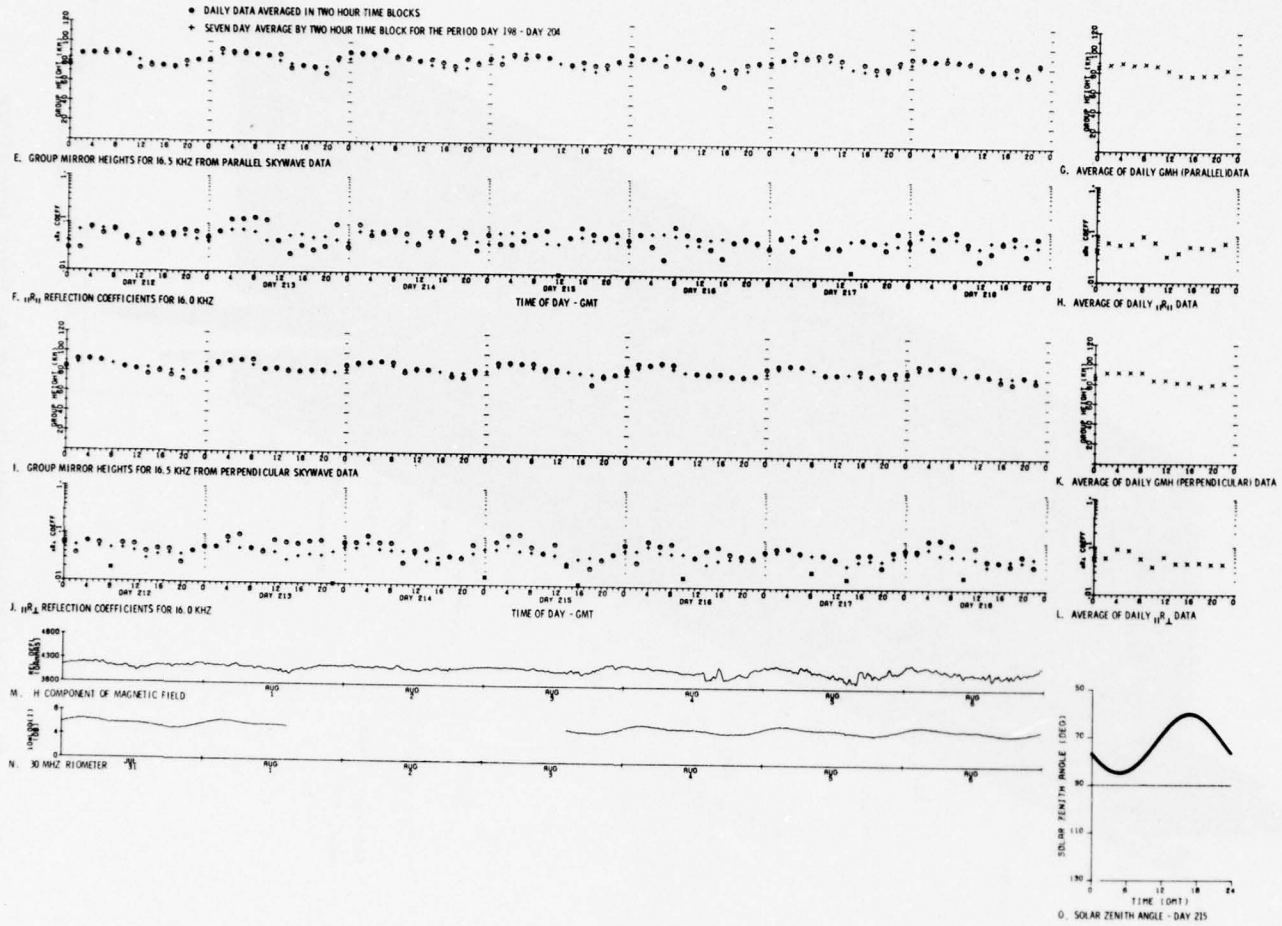


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 212 (31 Jul) — DAY 218 (6 Aug) 1977 (Cont)

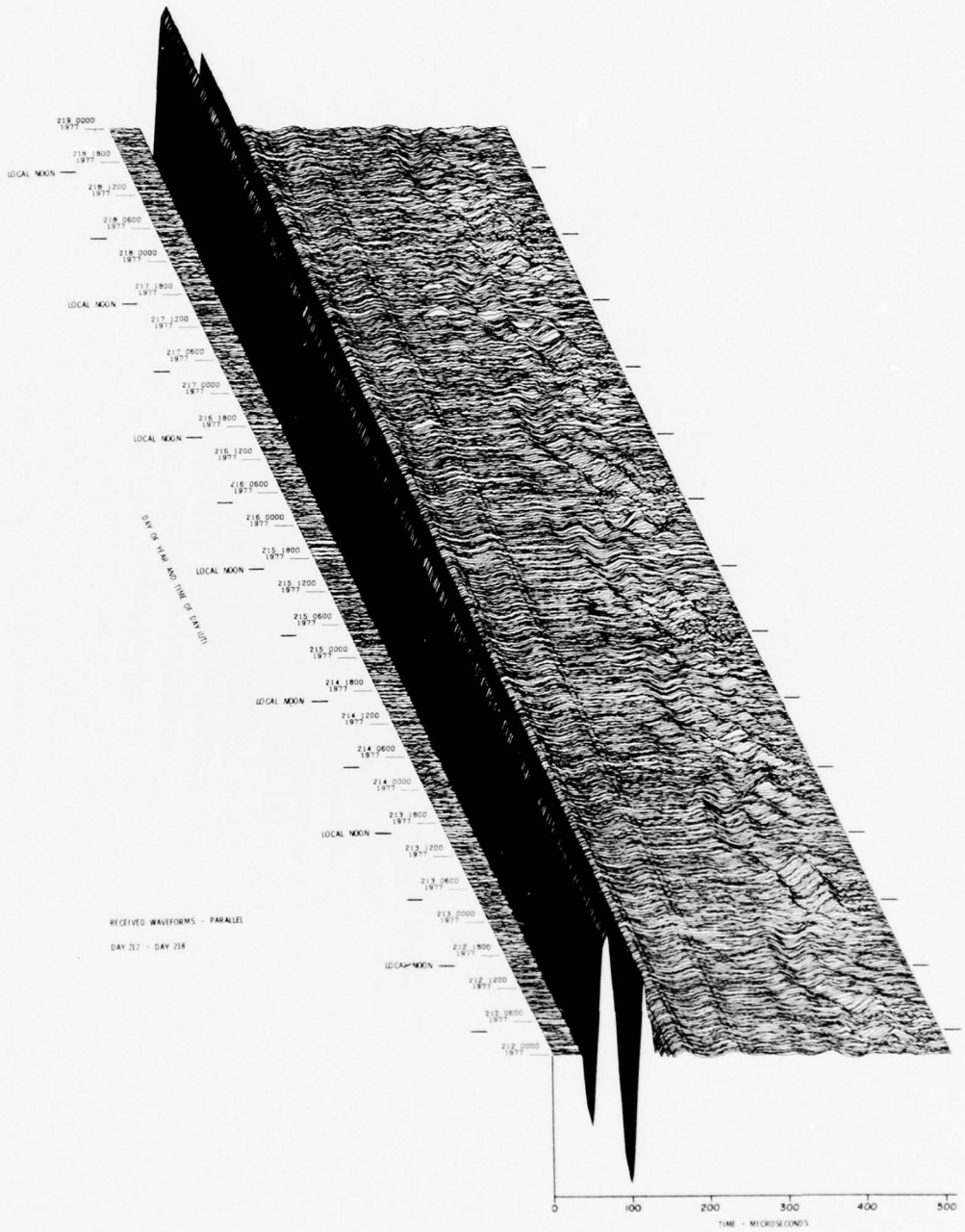


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 212 (31 Jul) – DAY 218 (6 Aug) 1977 (Cont)
Part R. ‖ Waveform Display

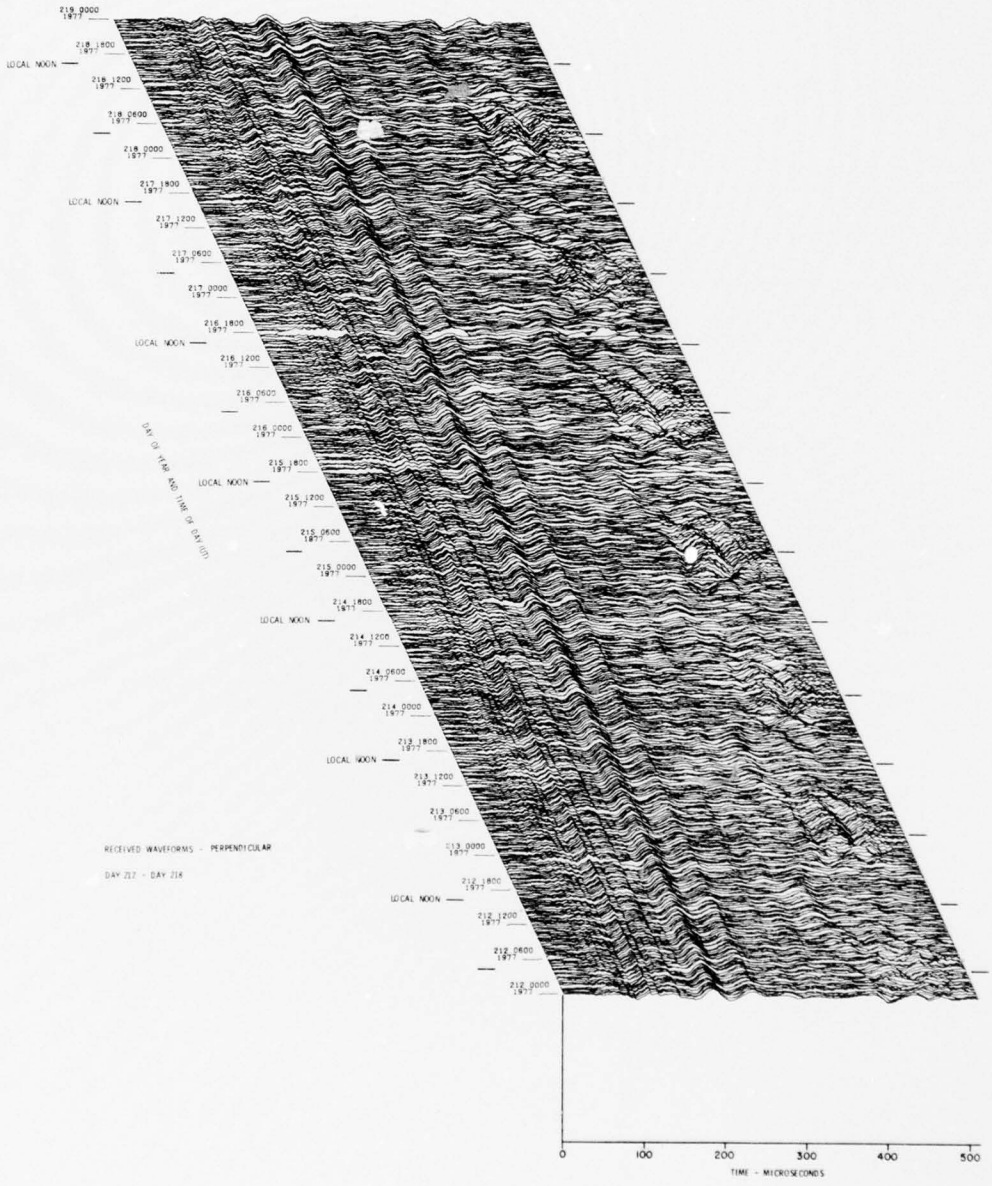
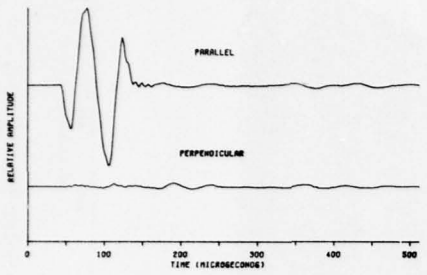
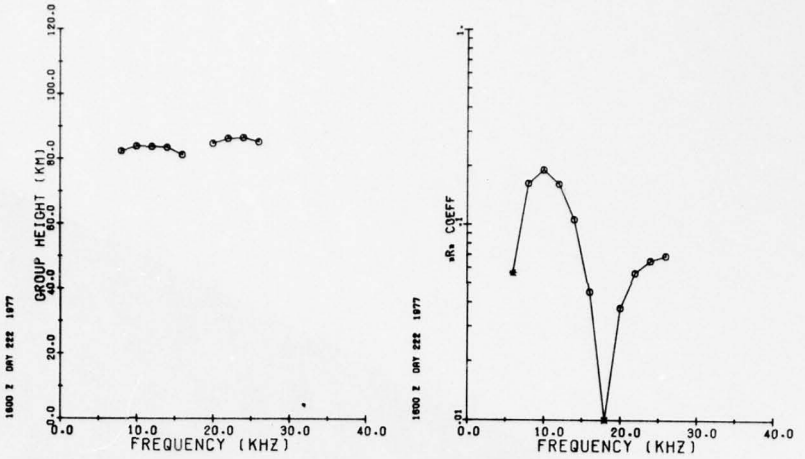


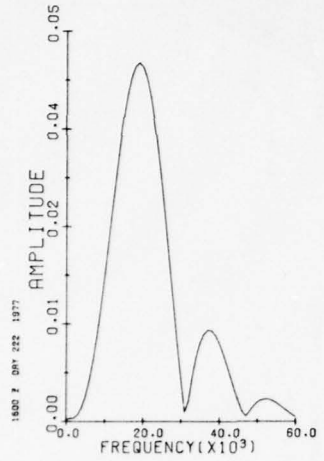
Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 212 (31 Jul) – DAY 218 (6 Aug) 1977 (Cont)
Part S. ⊥ Waveform Display



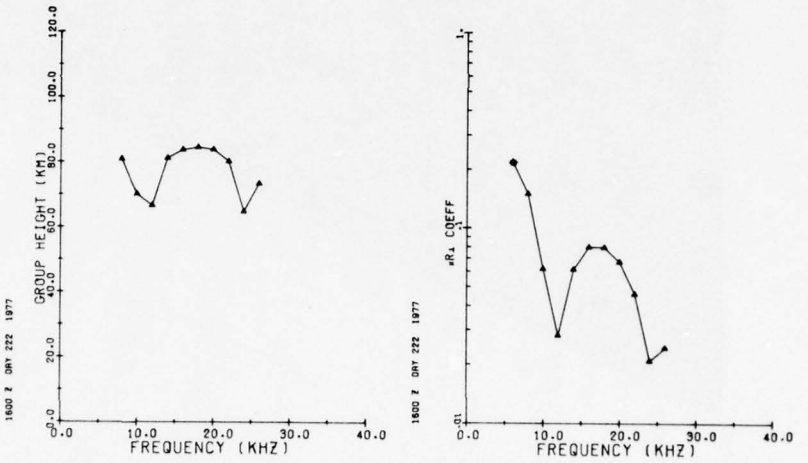
A. RECEIVED WAVEFORMS - 1600GMT, DAY 222



C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\parallel}$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\perp}$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 219 (7 Aug) – DAY 225 (13 Aug) 1977

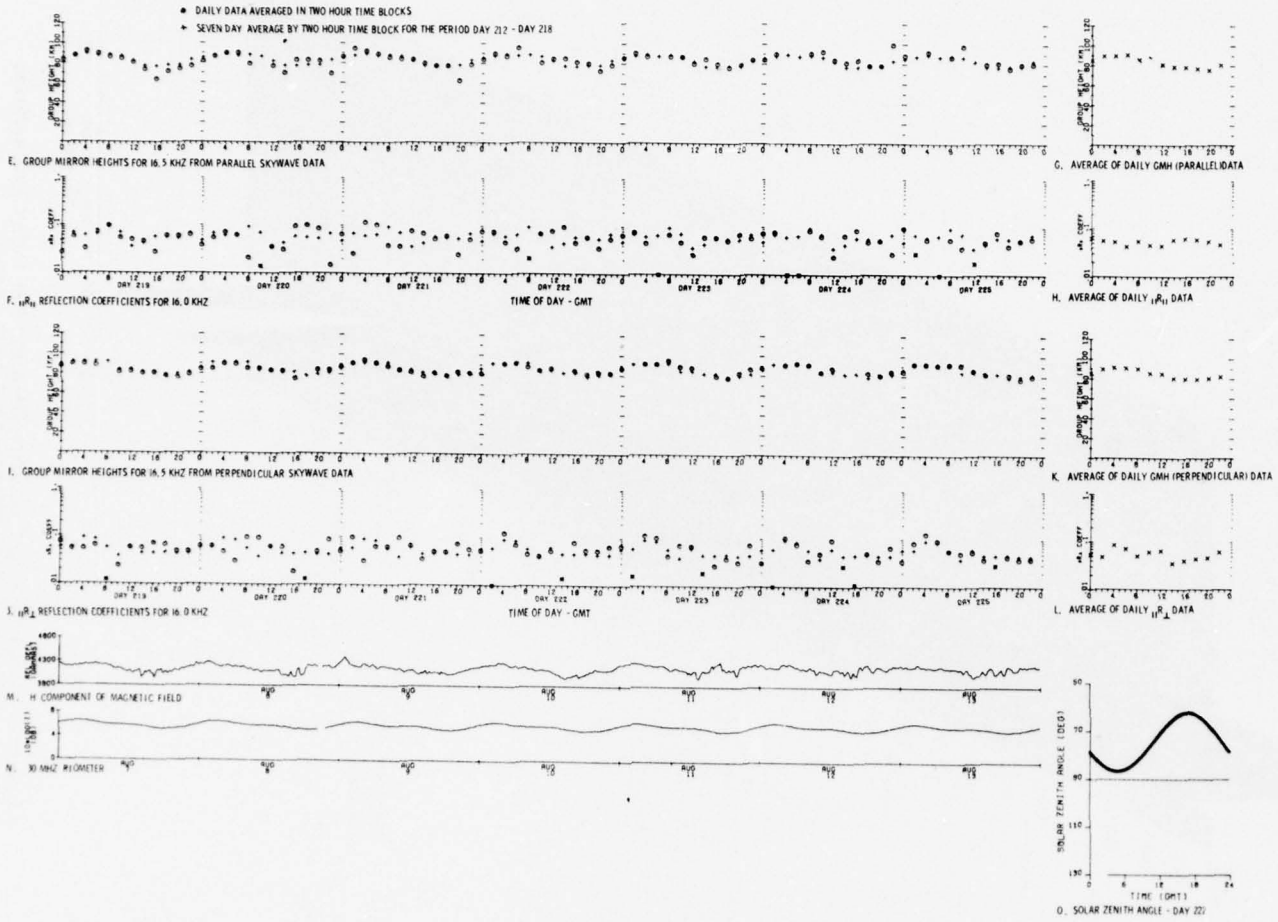


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 219 (7 Aug) – DAY 225 (13 Aug) 1977 (Cont)

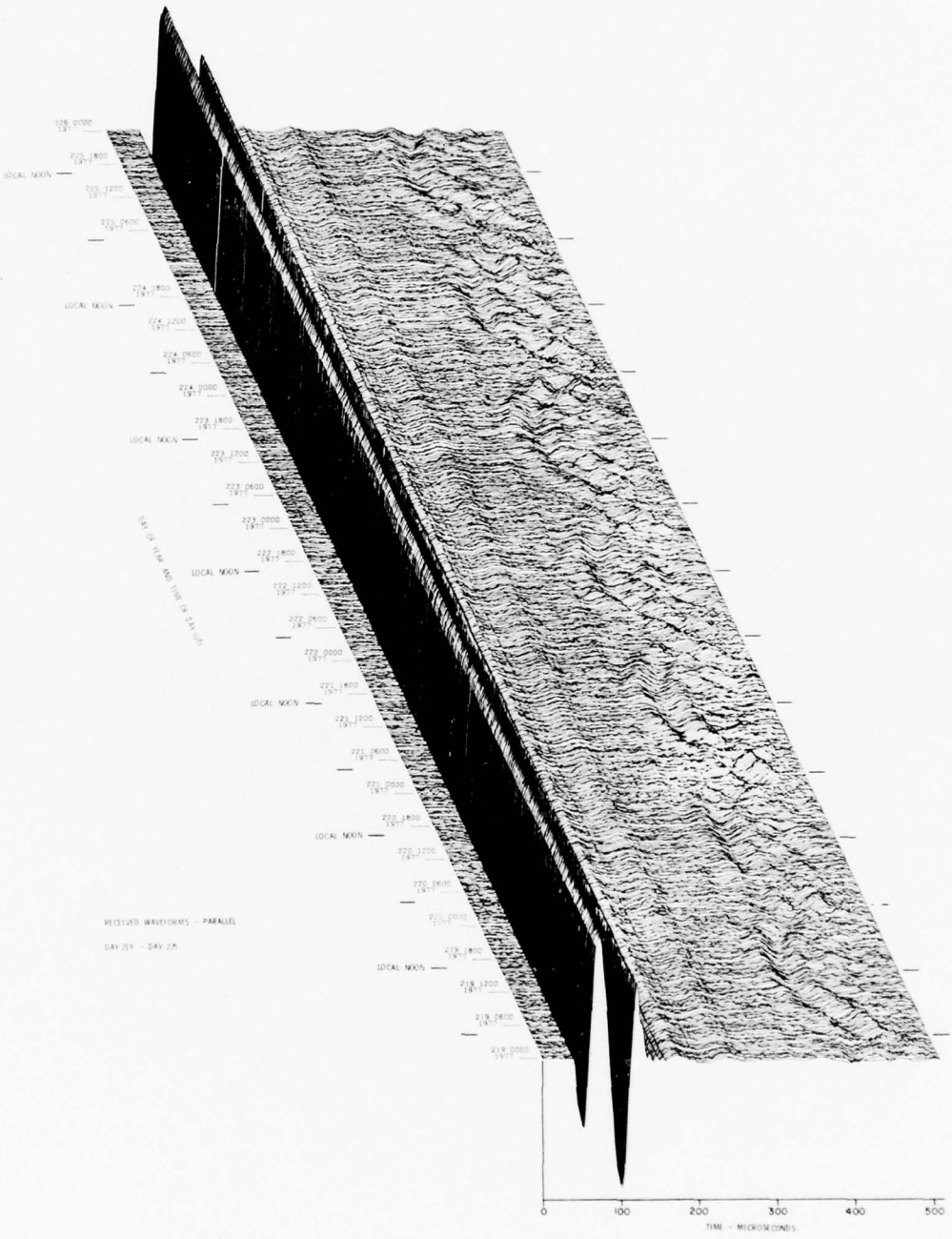


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 219 (7 Aug) — DAY 225 (13 Aug) 1977 (Cont)
Part R. // Waveform Display

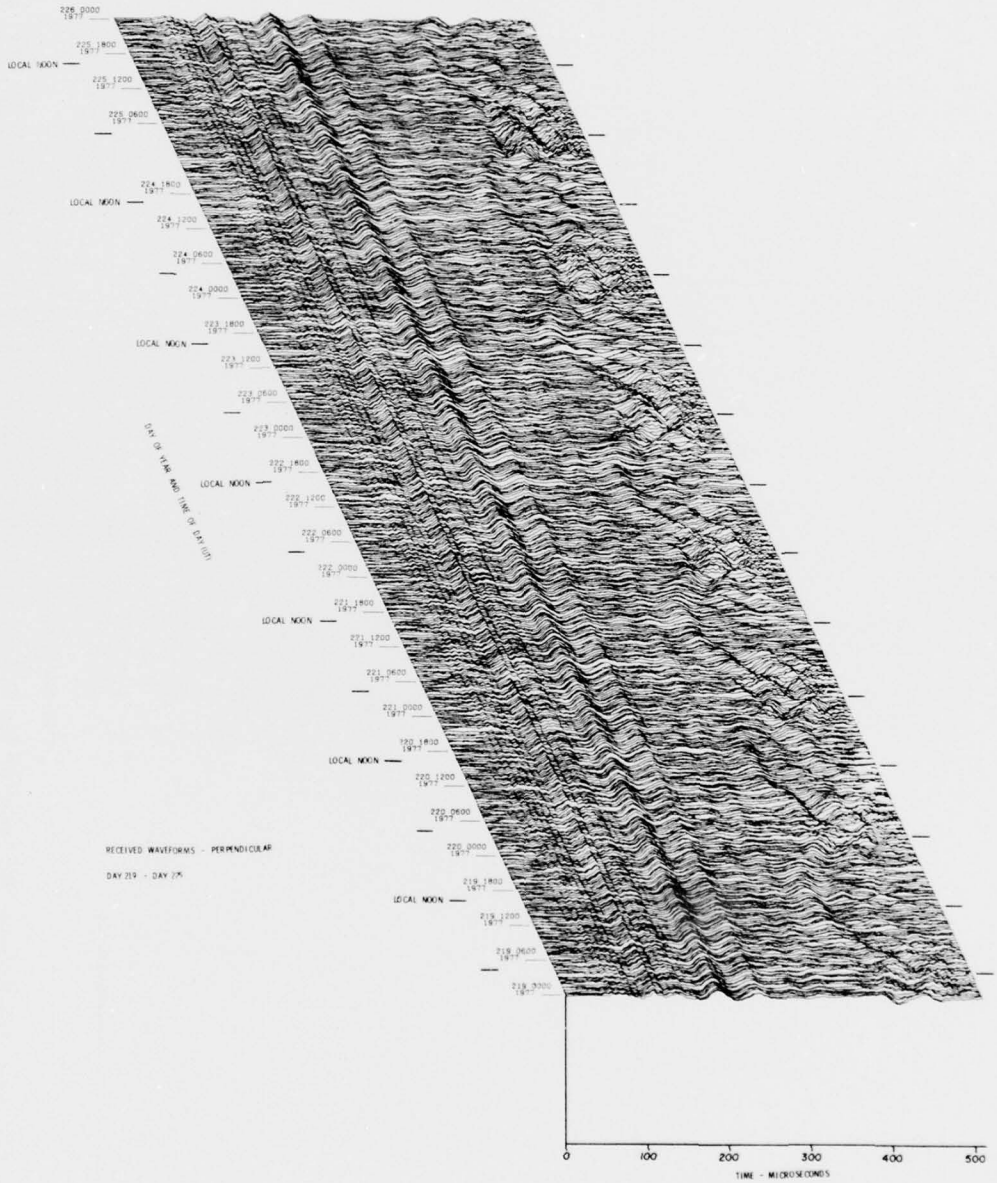
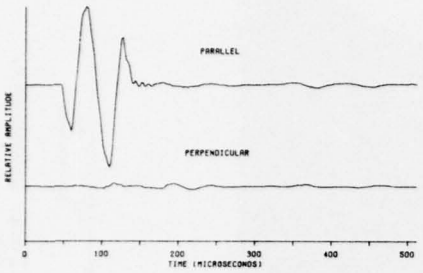
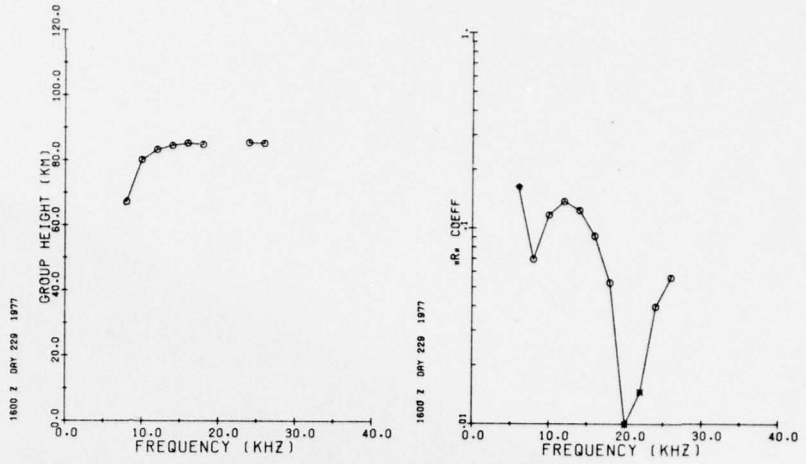


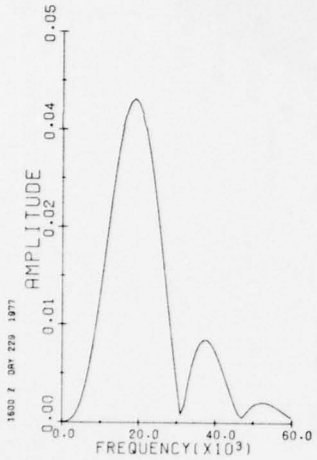
Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 219 (7 Aug) – DAY 225 (13 Aug) 1977 (Cont)
Part S. ⊥ Waveform Display



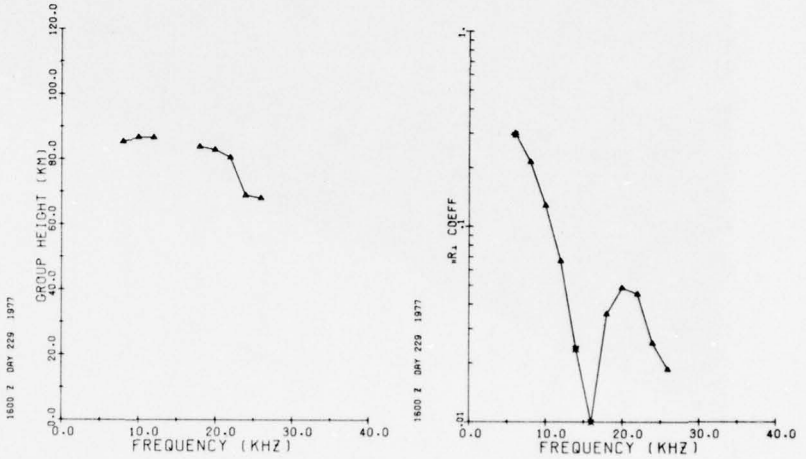
A. RECEIVED WAVEFORMS - 1600GMT, DAY 229



C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\parallel}$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE



D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\perp}$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 226 (14 Aug) — DAY 232 (20 Aug) 1977

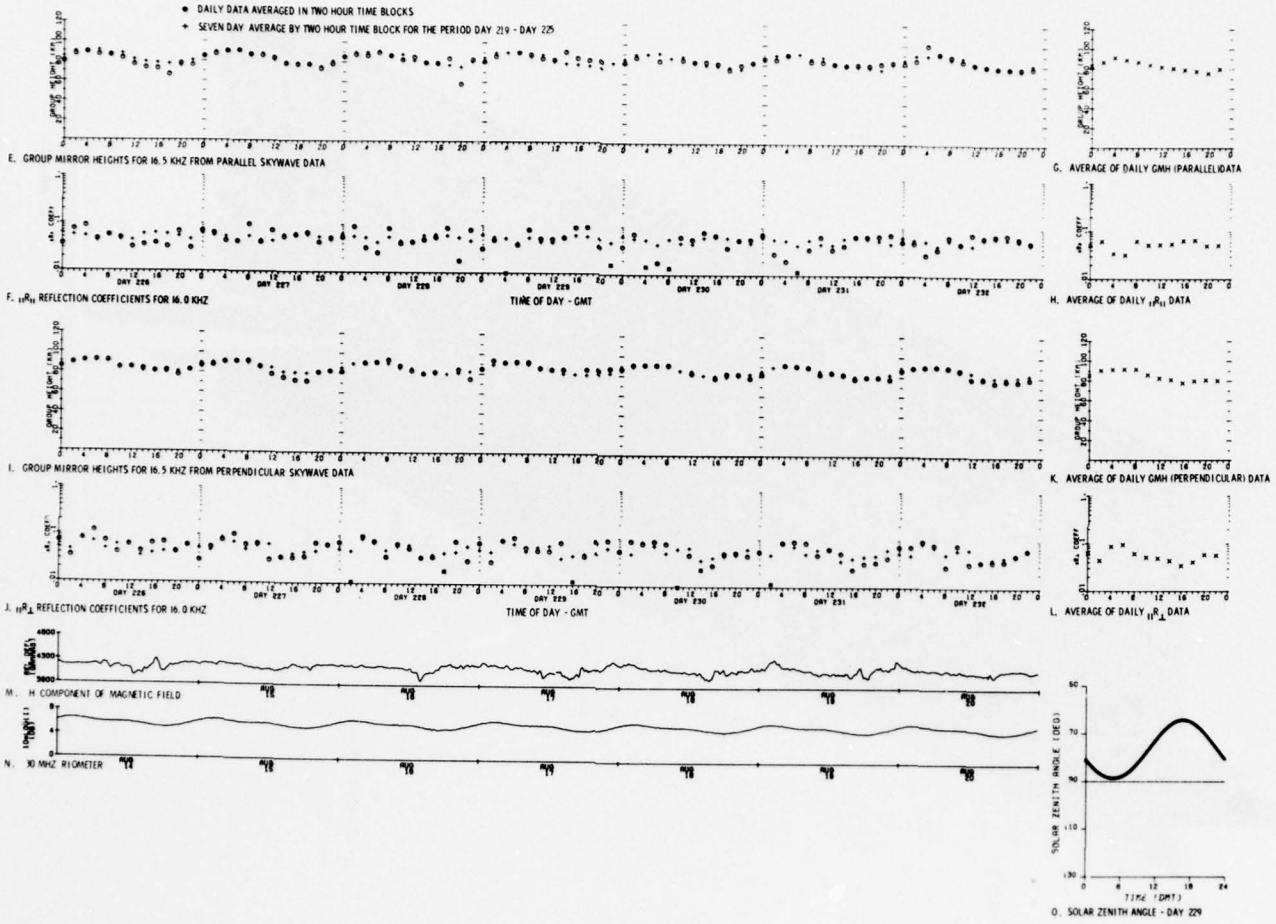


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 226 (14 Aug) – DAY 232 (20 Aug) 1977 (Cont)

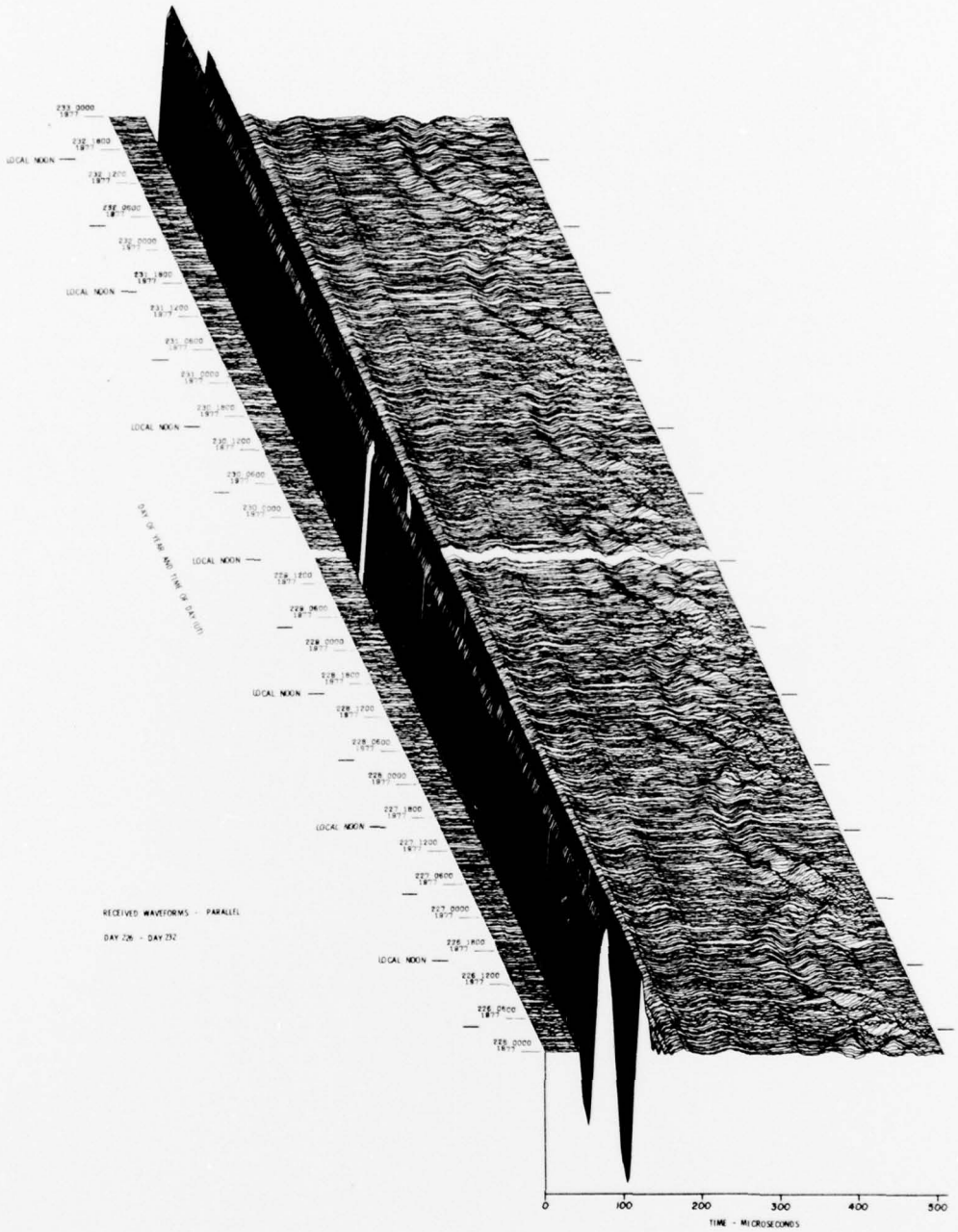


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 226 (14 Aug) — DAY 232 (20 Aug) 1977 (Cont)
Part R. ∥ Waveform Display

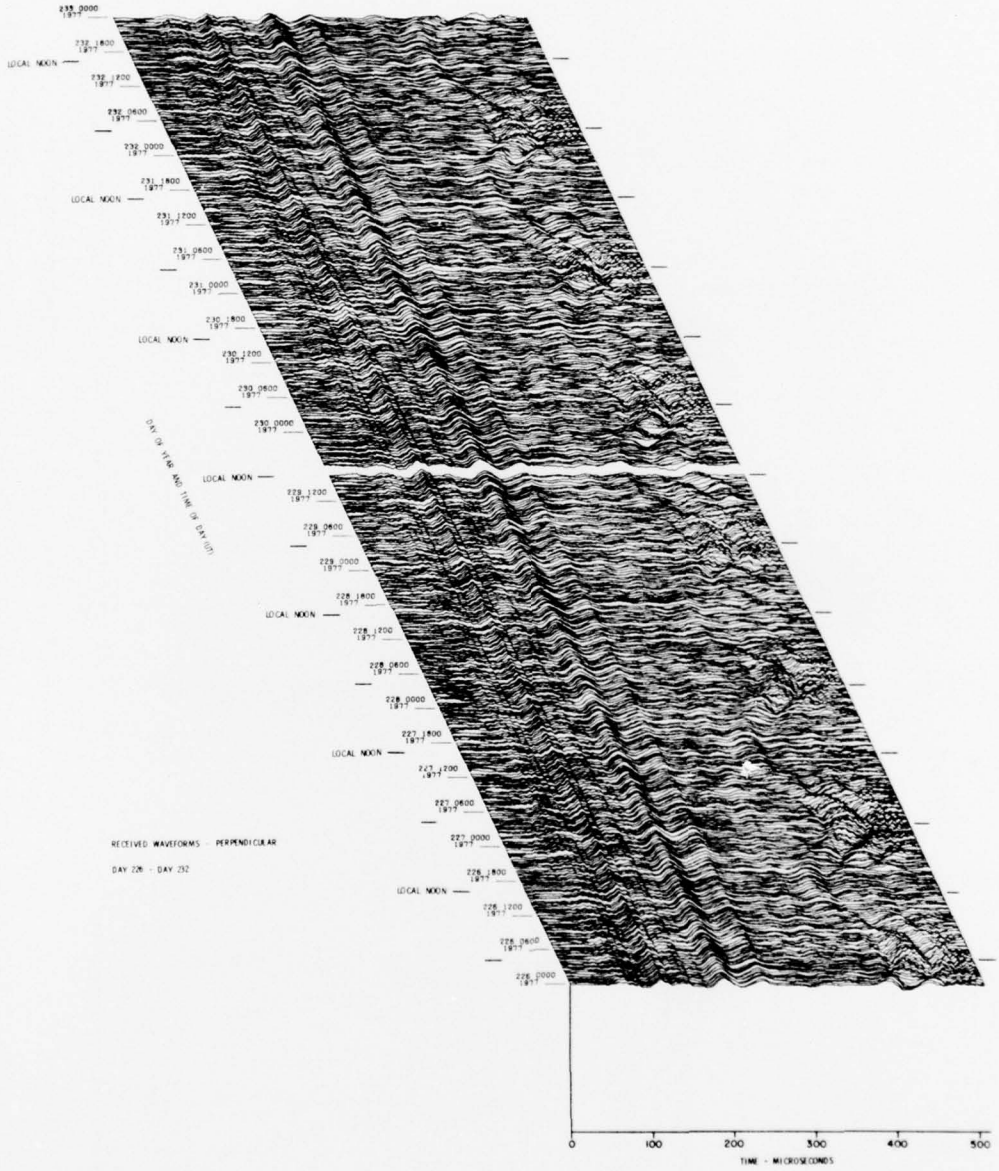
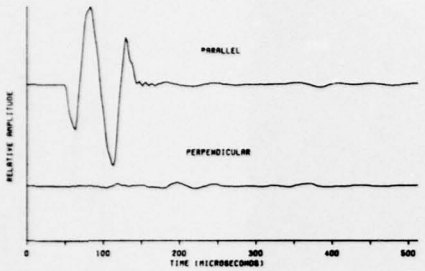
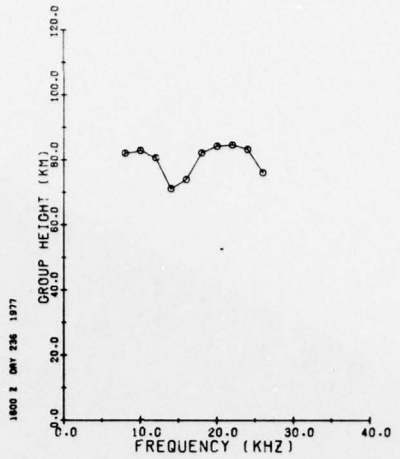
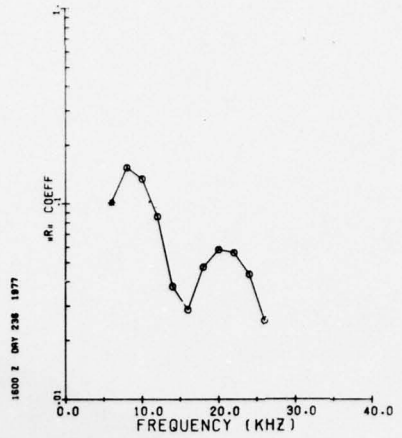


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 226 (14 Aug) – DAY 232 (20 Aug) 1977 (Cont)
Part S. ⊥ Waveform Display

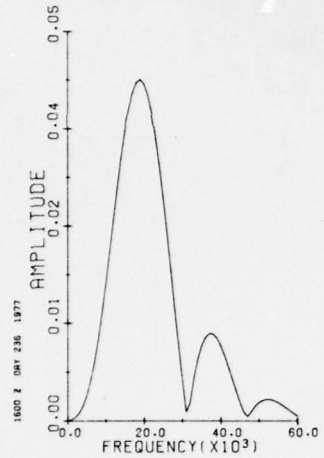


A. RECEIVED WAVEFORMS - 1600GMT, DAY 236

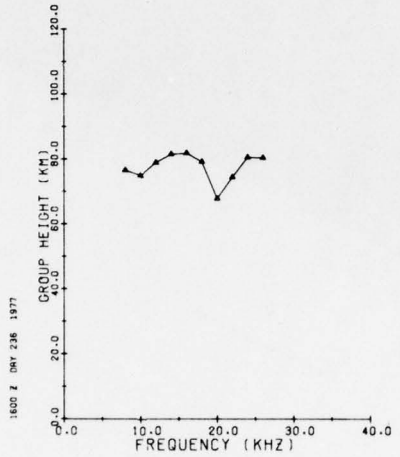


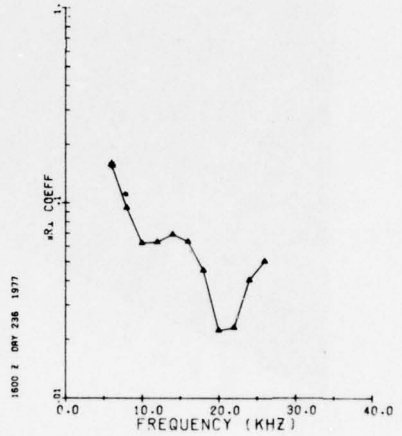


C. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\parallel}R_{\parallel}$ REFLECTION COEFFICIENTS FROM PARALLEL SKYWAVE DATA



B. FOURIER AMPLITUDE SPECTRUM OF GROUNDWAVE PULSE





D. GROUP MIRROR REFLECTION HEIGHTS AND ASSOCIATED $_{\perp}R_{\perp}$ REFLECTION COEFFICIENTS FROM PERPENDICULAR SKYWAVE DATA

Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 233 (21 Aug) — DAY 239 (27 Aug) 1977

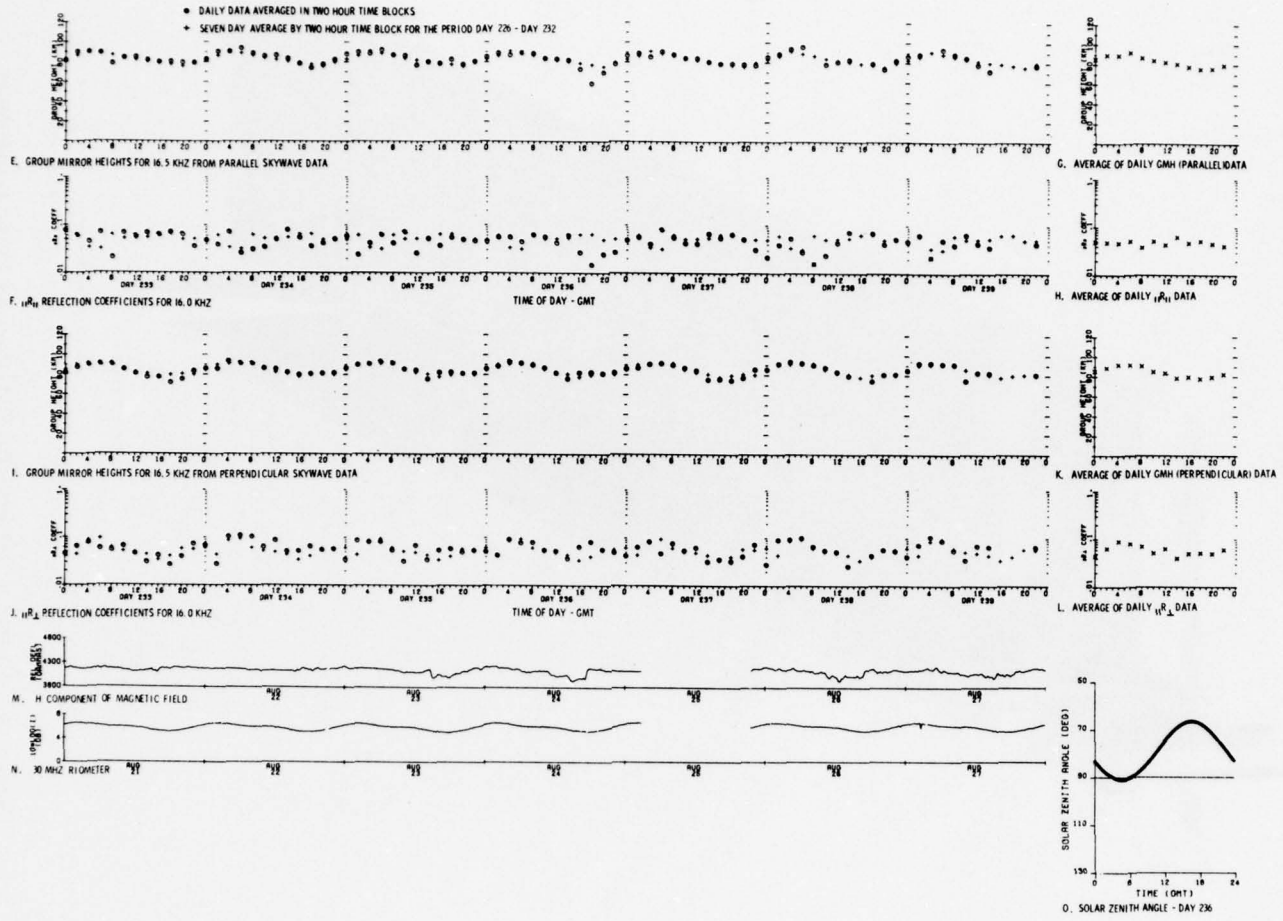


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 233 (21 Aug) — DAY 239 (27 Aug) 1977 (Cont)

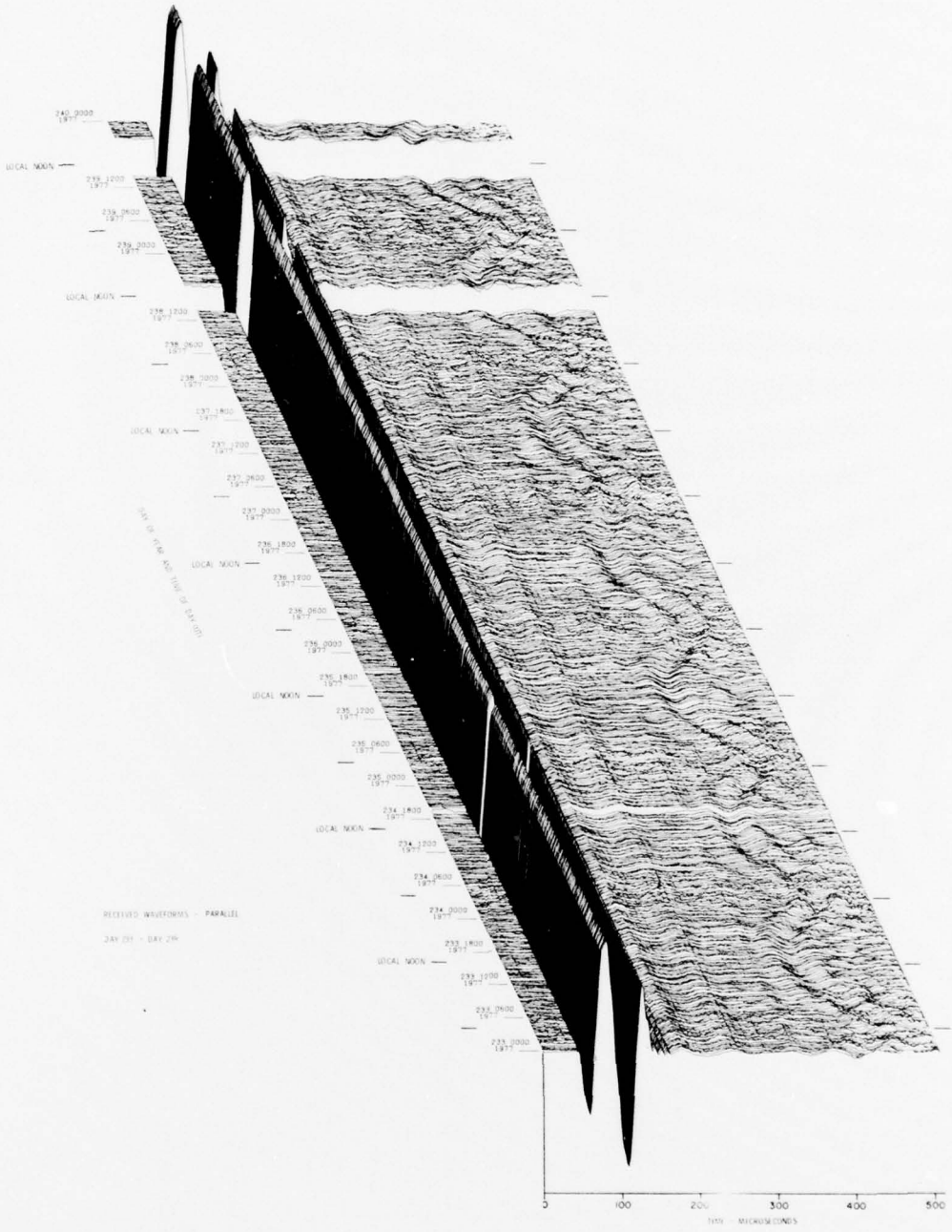


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 233 (21 Aug) – DAY 239 (27 Aug) 1977 (Cont)
Part R. ll Waveform Display

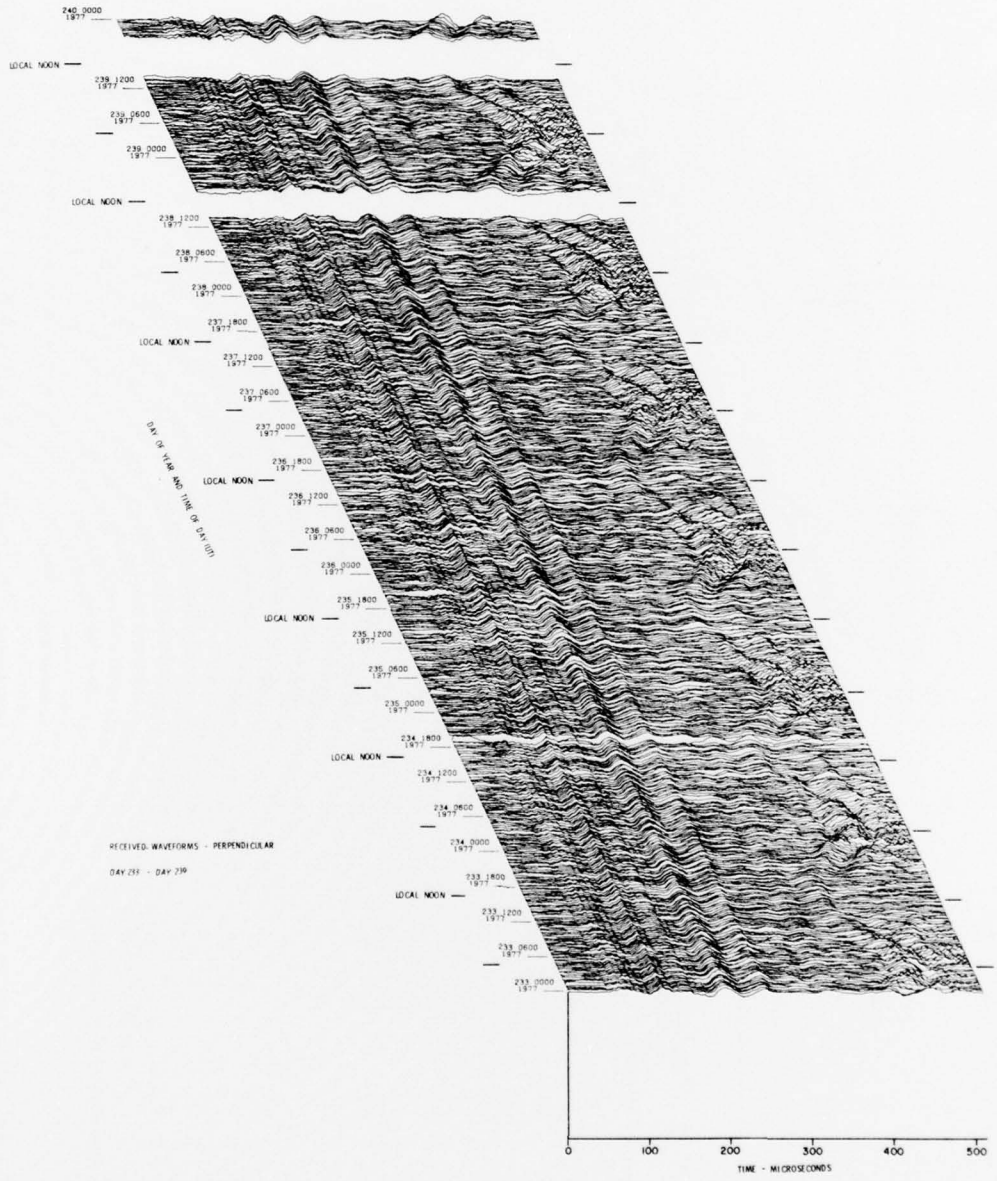


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 233 (21 Aug) – DAY 239 (27 Aug) 1977 (Cont)
Part S. ⊥ Waveform Display

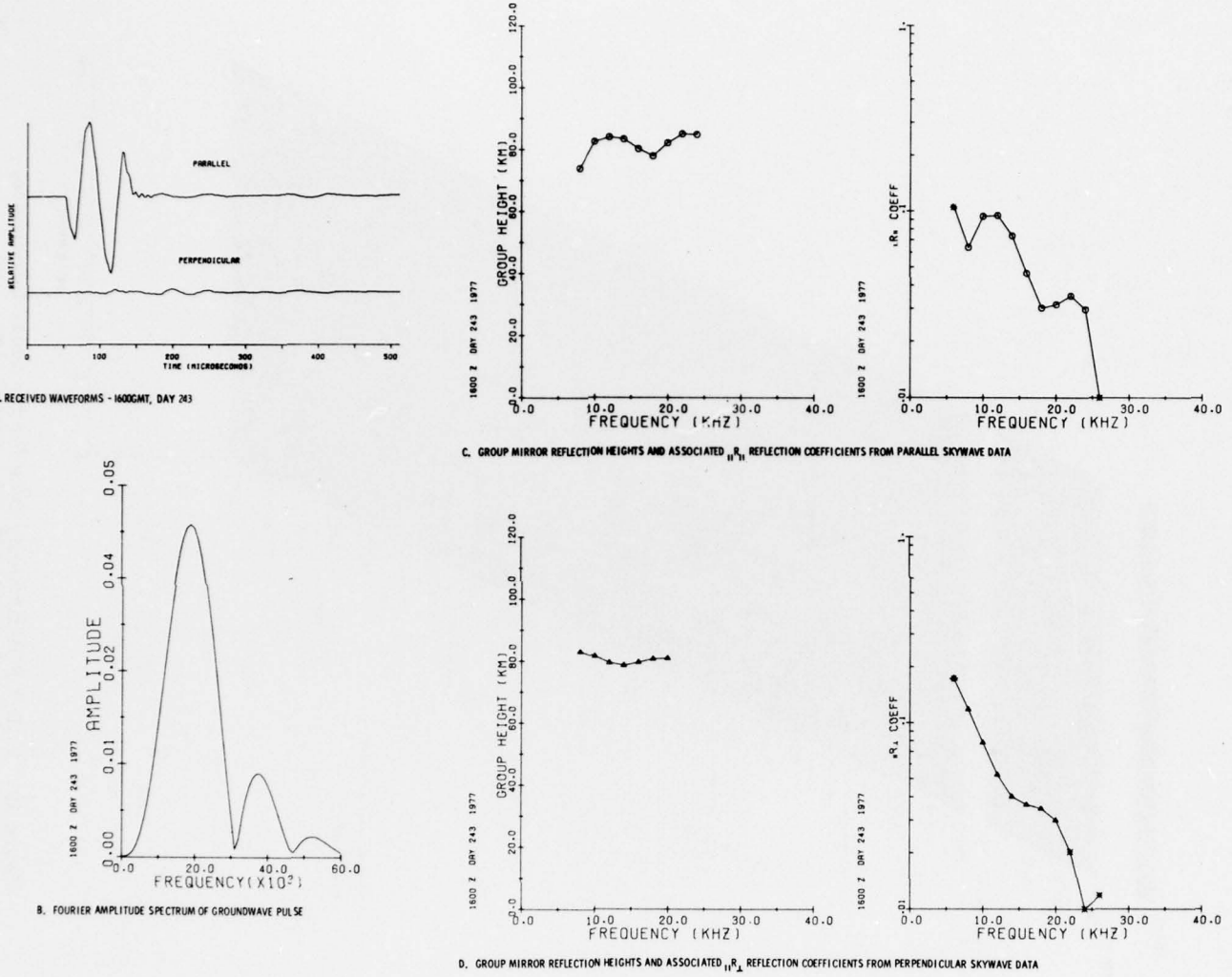


Figure 20. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 240 (28 Aug) — DAY 246 (3 Sep) 1977

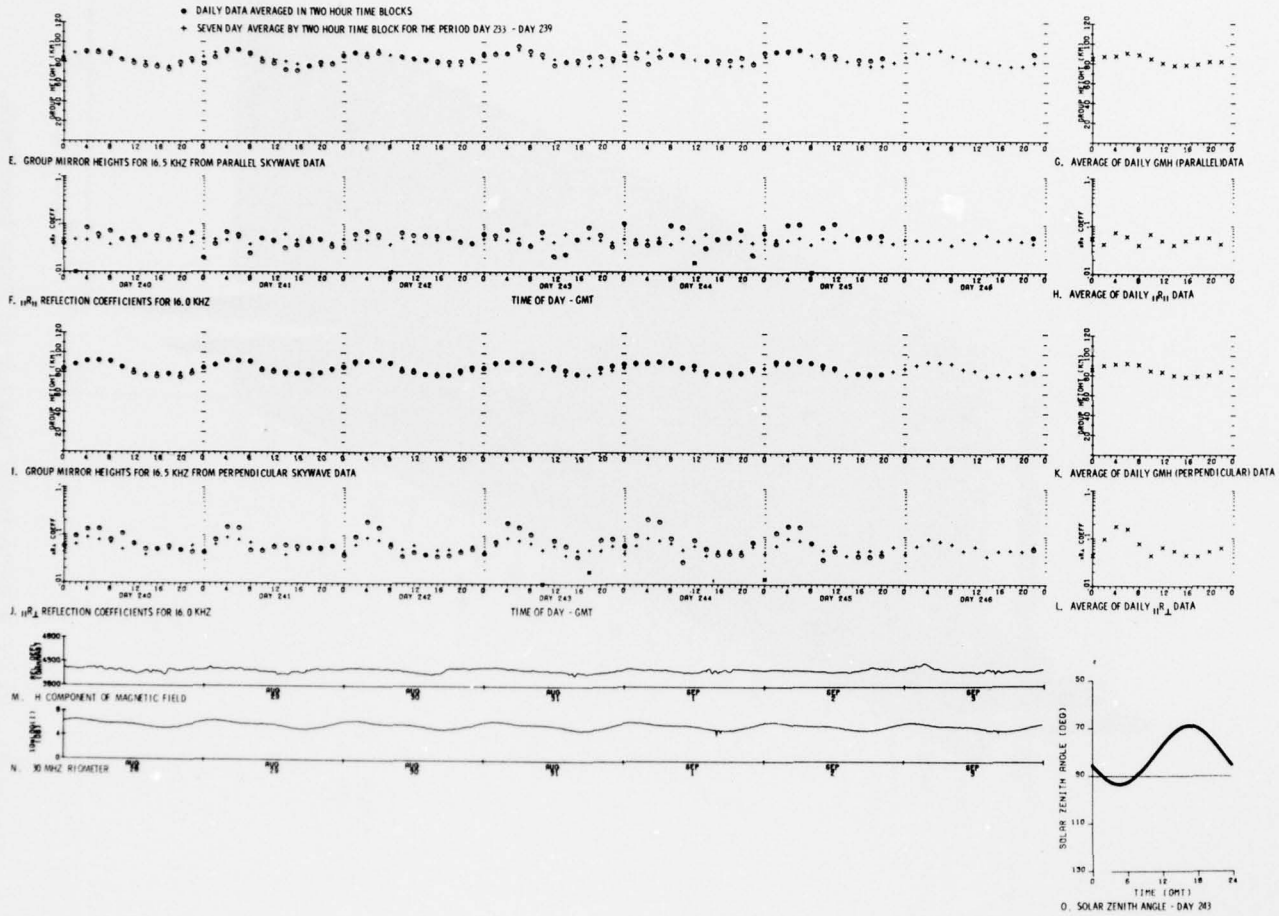


Figure 20. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 240 (28 Aug) — DAY 246 (3 Sep) 1977 (Cont)

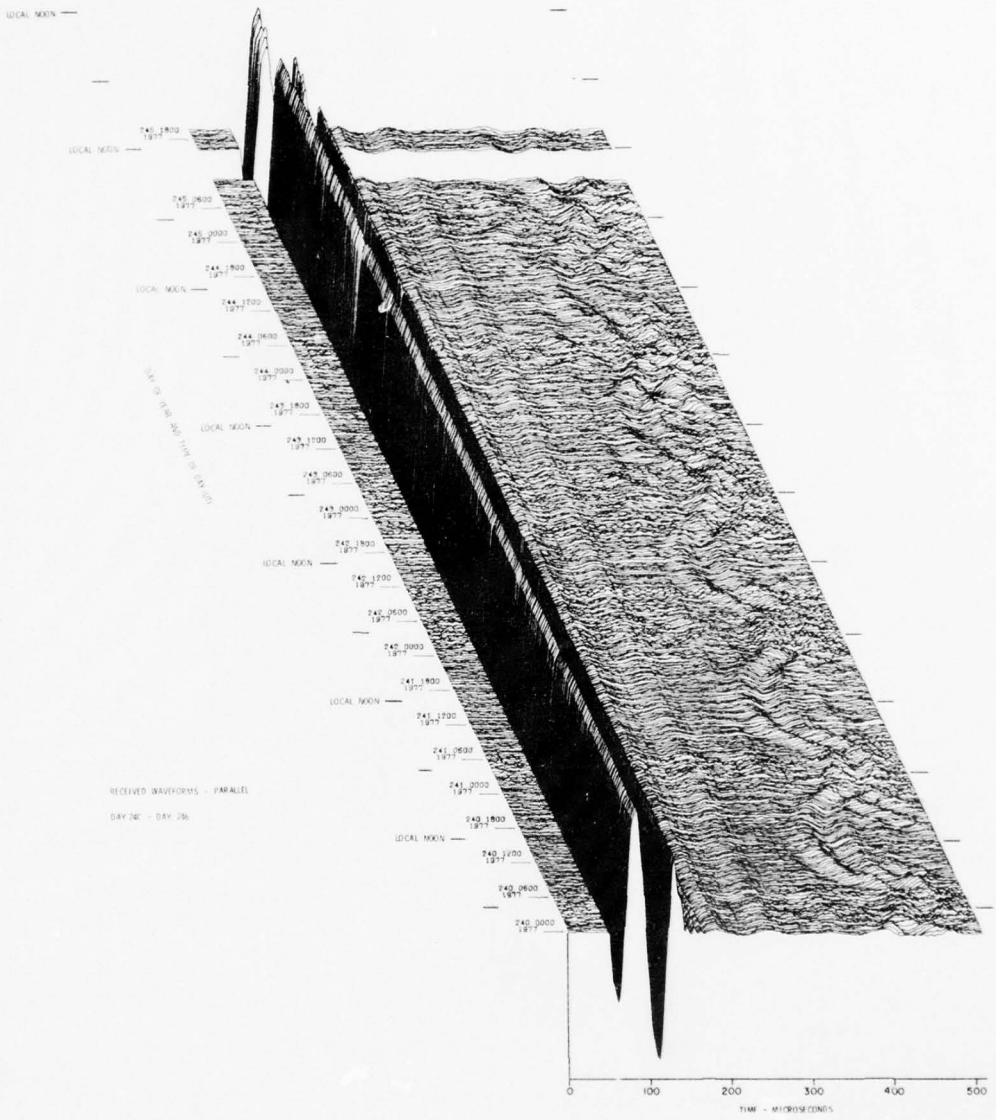


Figure 20. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 240 (28 Aug) – DAY 246 (3 Sep) 1977 (cont)
Part R. ∥ Waveform Display

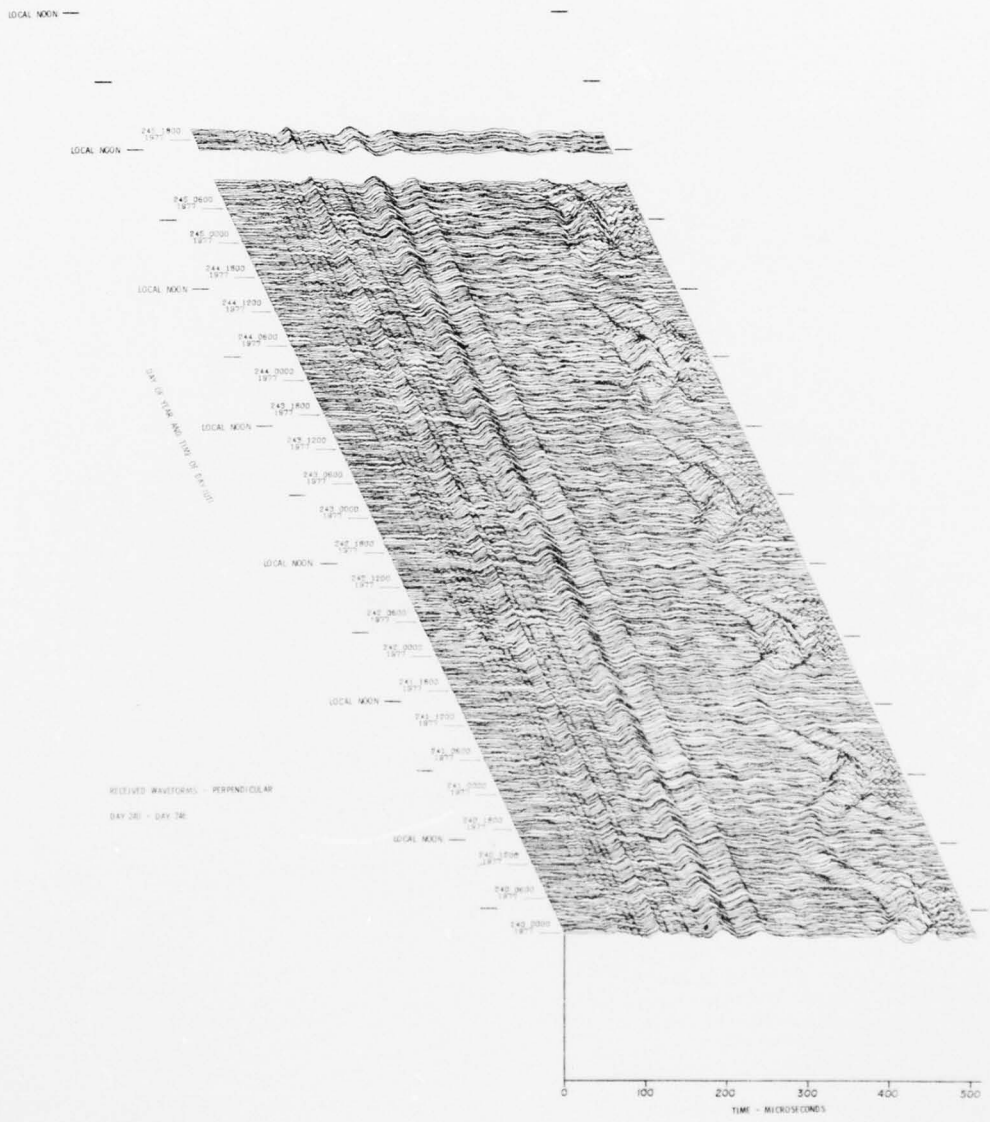


Figure 20. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 240 (28 Aug) – DAY 246 (3 Sep) 1977 (Cont)
Part S. ⊥ Waveform Display

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11. Rasmussen, J. E., Turtle, J. P., Pagliarulo, R. P., and Klemetti, W. I. (1977) VLF/LF Reflectivity of the Polar Ionosphere, 1 August 1976 – 1 January 1977, RADC-TR-77-141.

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